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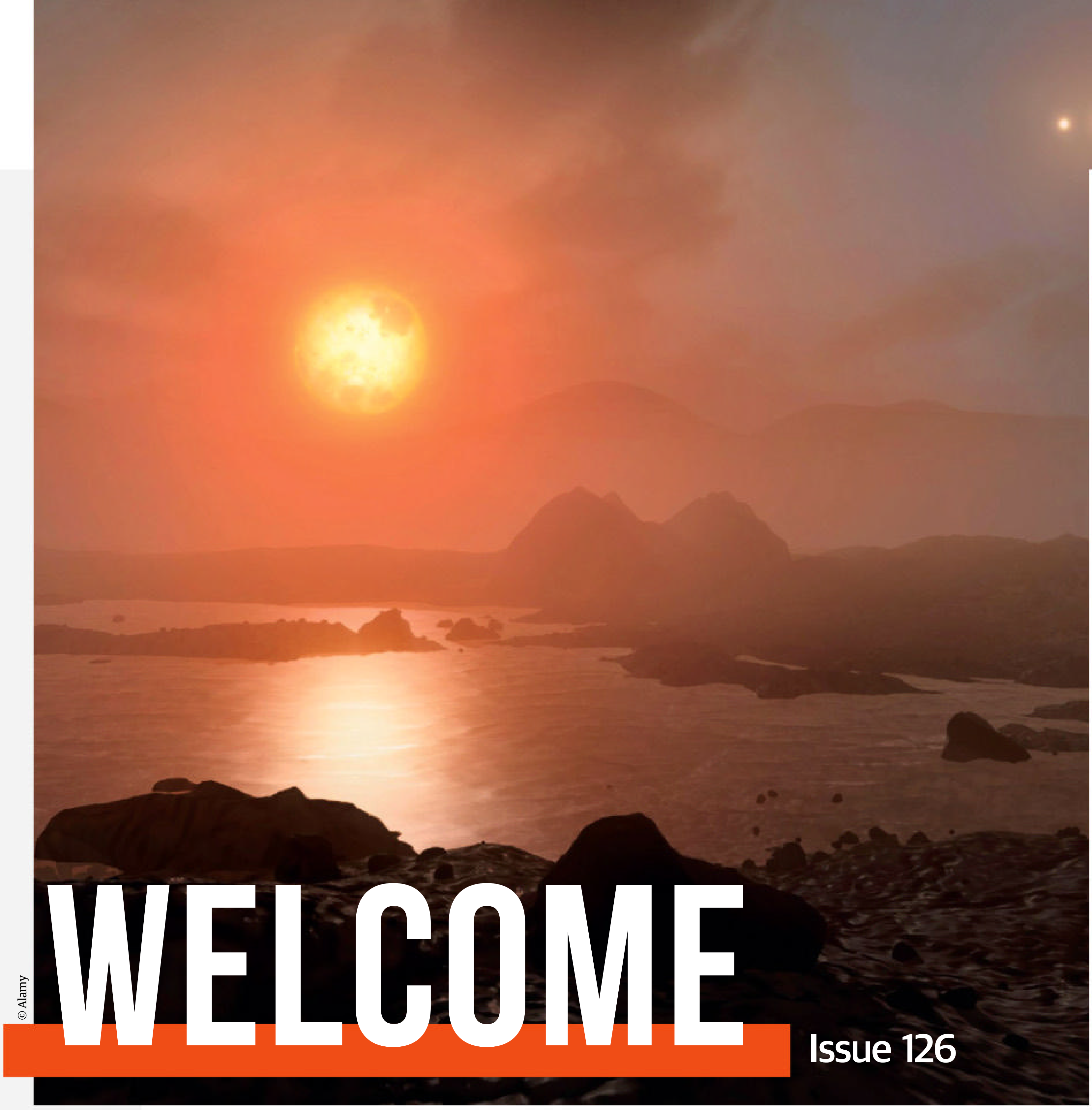

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WELCOME

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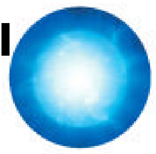

The Big Bang
How did the event that brought our universe into existence really happen? 56

As I write this, we're in the first few days of 2022. The James Webb Space Telescope has launched and unfolded, NASA is gearing up for the launch of its next Moon mission, Artemis 1, and Comet Leonard put on a final show before falling out of view for skywatchers – I hope you managed to catch it in December!

While we've reached 2022 here on Earth, we head to some planets where the measure of time is very different: join us as we take a tour of exoplanets, worlds that are – in most instances – quite different to what we're used to in the Solar System. From searingly hot Jupiters to beefed-up super-Earths, you'll discover where we're at in our plans to find Earth 2.0, the weirdest worlds we've ever discovered and what the James Webb Space Telescope is likely to reveal about the far-flung places that litter our galaxy.

Turn to page 28 and you'll discover everything there is to know about Artemis 1, the first in a series of missions that will land humanity on the surface of the Moon again. It's currently tipped to launch on 12 March, so be sure to follow us on social media for the latest information and, of course, we'll be sure to keep you updated in the magazine too. I hope you enjoy the issue, and I look forward to seeing you next time!

GEMMA LAVENDER
CONTENT DIRECTOR

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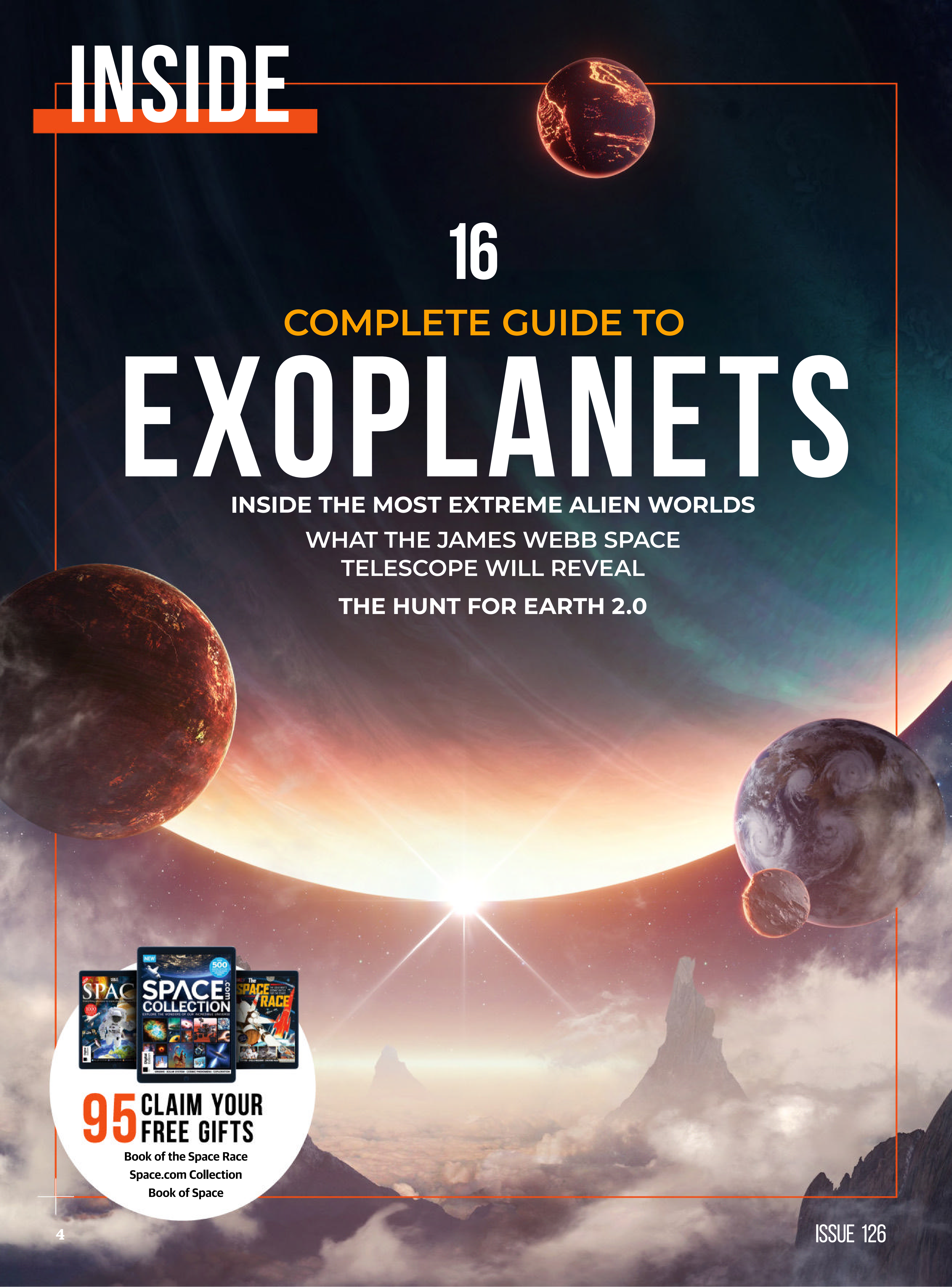

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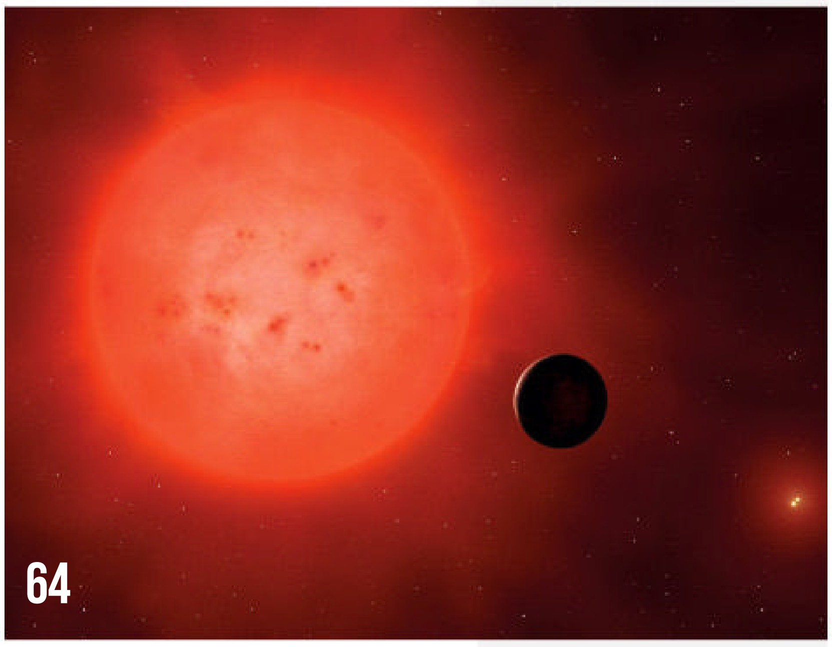
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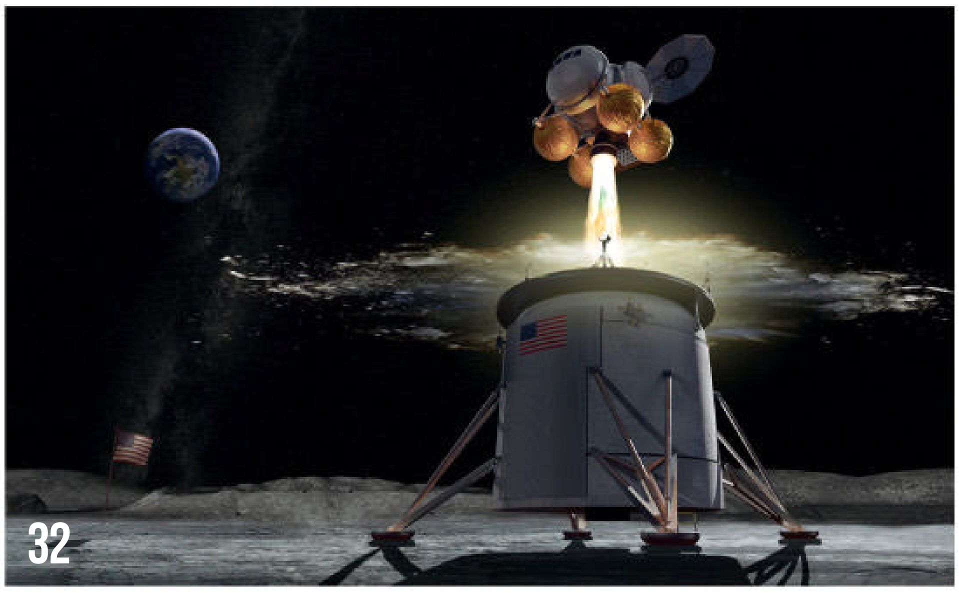
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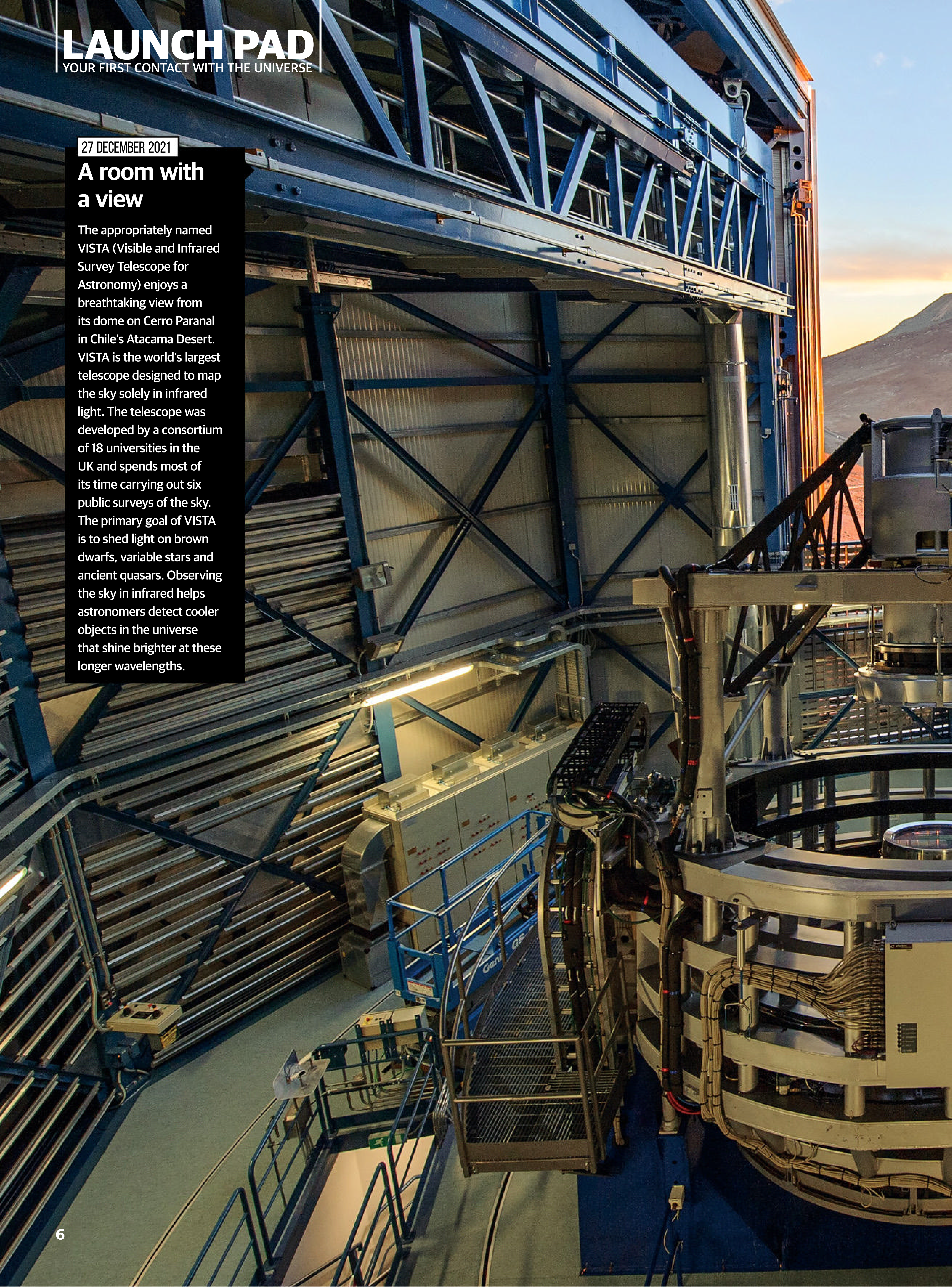

27 DECEMBER 2021

A room with a view

The appropriately named VISTA (Visible and Infrared Survey Telescope for Astronomy) enjoys a breathtaking view from its dome on Cerro Paranal in Chile's Atacama Desert. VISTA is the world's largest telescope designed to map the sky solely in infrared light. The telescope was developed by a consortium of 18 universities in the UK and spends most of its time carrying out six public surveys of the sky. The primary goal of VISTA is to shed light on brown dwarfs, variable stars and ancient quasars. Observing the sky in infrared helps astronomers detect cooler objects in the universe that shine brighter at these longer wavelengths.

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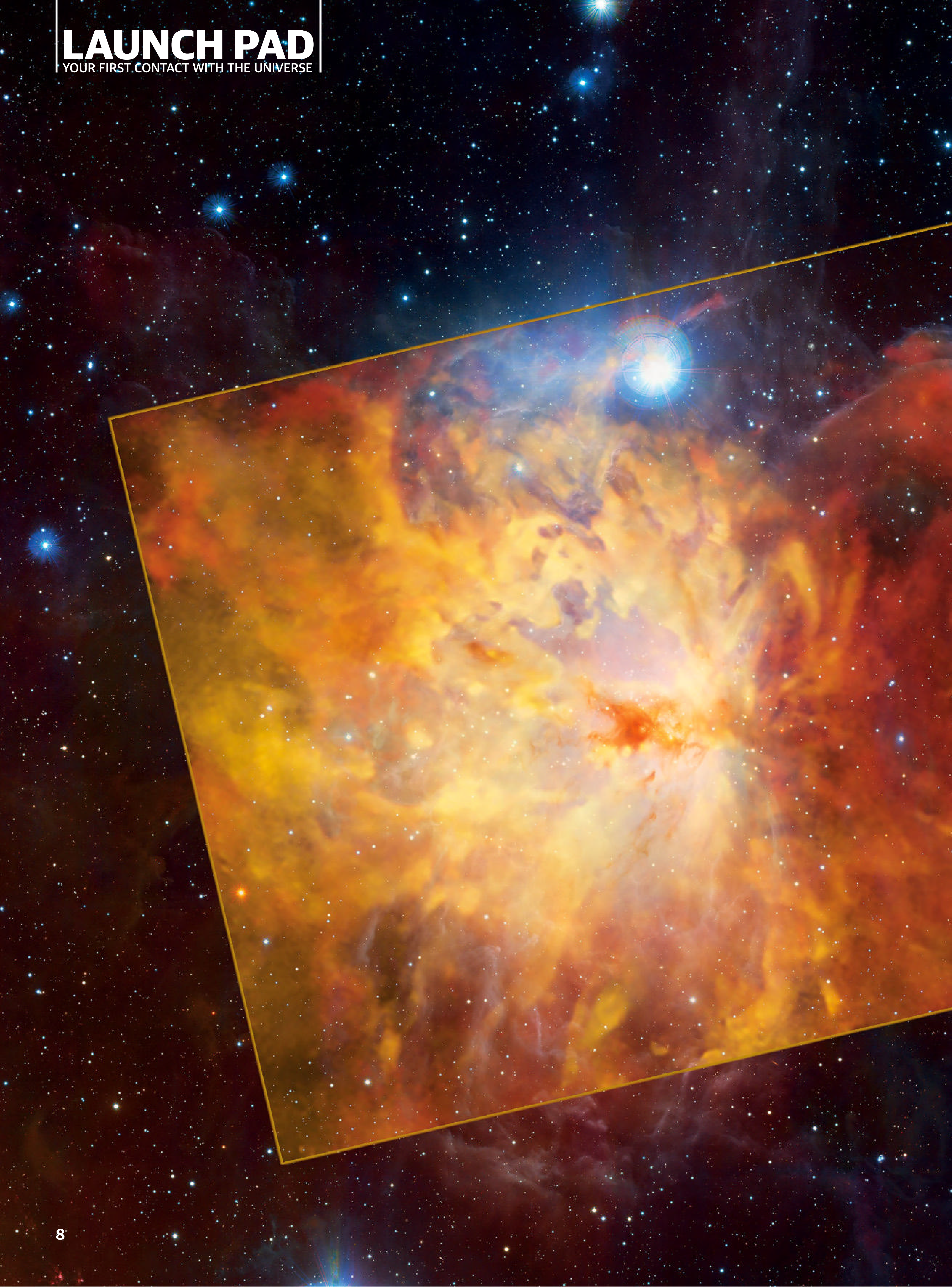

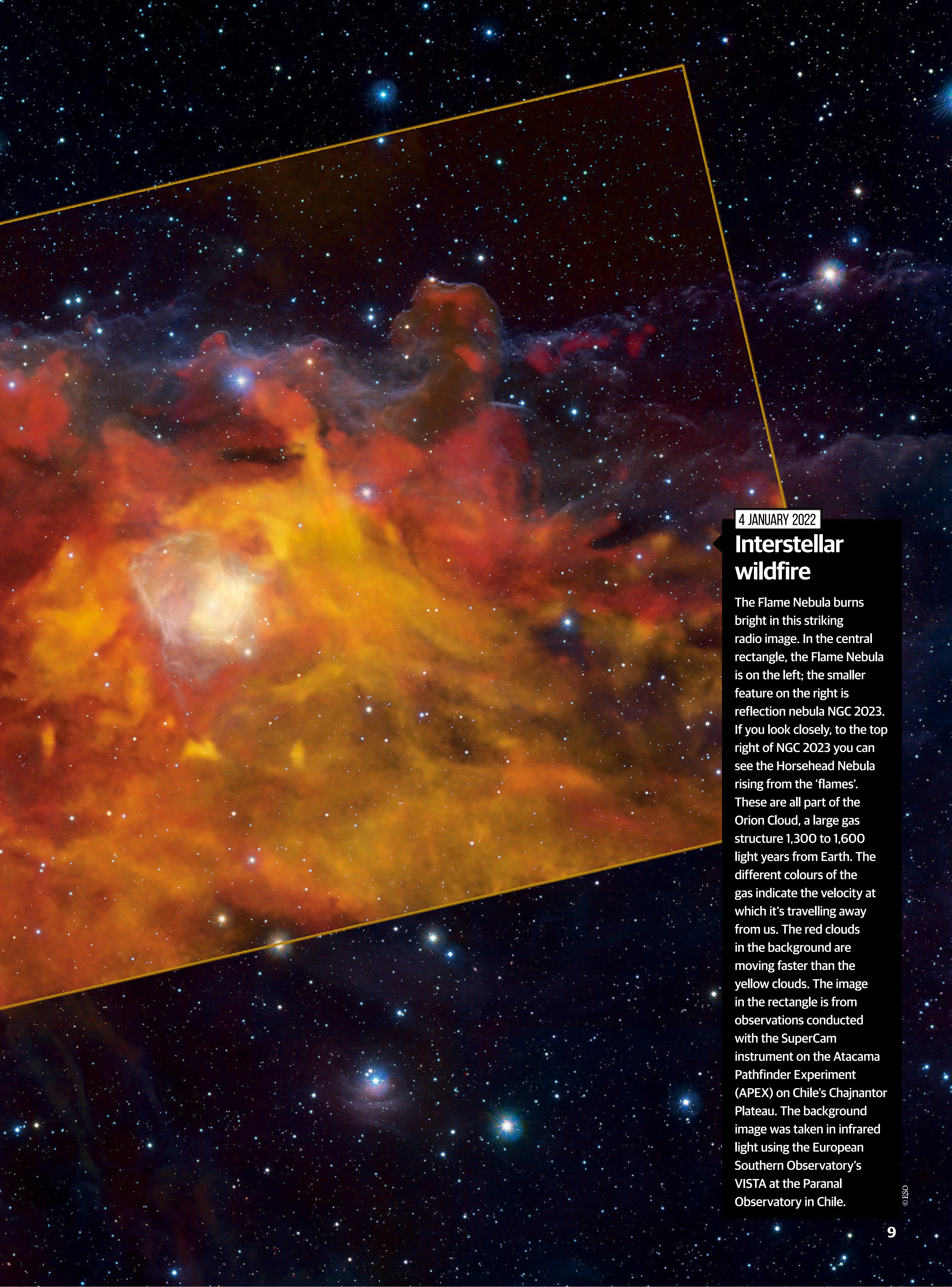

4 JANUARY 2022

Interstellar wildfire

The Flame Nebula burns bright in this striking radio image. In the central rectangle, the Flame Nebula is on the left; the smaller feature on the right is reflection nebula NGC 2023. If you look closely, to the top right of NGC 2023 you can see the Horsehead Nebula rising from the 'flames'. These are all part of the Orion Cloud, a large gas structure 1,300 to 1,600 light years from Earth. The different colours of the gas indicate the velocity at which it's travelling away from us. The red clouds in the background are moving faster than the yellow clouds. The image in the rectangle is from observations conducted with the SuperCam instrument on the Atacama Pathfinder Experiment (APEX) on Chile's Chajnantor Plateau. The background image was taken in infrared light using the European Southern Observatory's VISTA at the Paranal Observatory in Chile.

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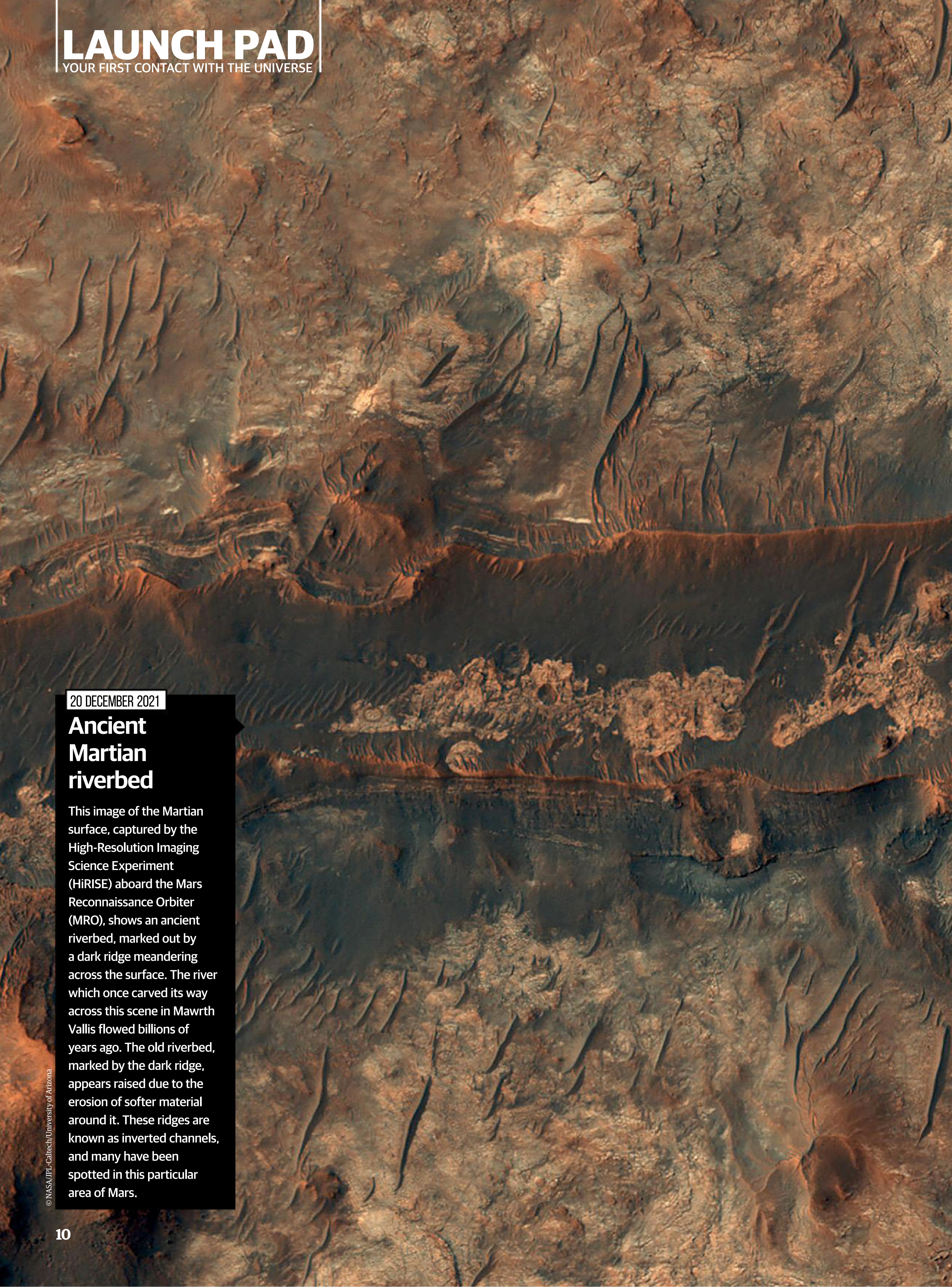

20 DECEMBER 2021

Ancient Martian riverbed

This image of the Martian surface, captured by the High-Resolution Imaging Science Experiment (HiRISE) aboard the Mars Reconnaissance Orbiter (MRO), shows an ancient riverbed, marked out by a dark ridge meandering across the surface. The river which once carved its way across this scene in Mawrth Vallis flowed billions of years ago. The old riverbed, marked by the dark ridge, appears raised due to the erosion of softer material around it. These ridges are known as inverted channels, and many have been spotted in this particular area of Mars.

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JAMES WEBB SPACE TELESCOPE HAS ENOUGH FUEL FOR MORE THAN TEN YEARS OF SCIENCE

Words by Meghan Bartels

NASA's newest flagship space observatory should have enough fuel to more than double its minimum mission life peering into the history of the universe. The long-awaited James Webb Space Telescope, a collaboration with the Canadian and European space agencies led by NASA, launched into space on 25 December 2021 aboard an Ariane 5 rocket.

Often billed as the successor to the agency's iconic Hubble Space Telescope, Webb – also known as the JWST – is designed to focus on infrared light, giving astronomers a look at the earliest days of the universe. Despite an ambitious science agenda, the mission was designed with just a five-year minimum lifetime. But with the observatory finally in space, NASA is confident that it will have enough fuel to see much more use than that.

"The Webb team has analysed its initial trajectory and determined the observatory should have enough propellant to allow support of science operations in orbit for significantly more than a ten-year science lifetime," said NASA officials. "For comparison, the Hubble Space Telescope has lasted more than 30 years.

The agency noted that it can't provide a specific estimate for how long the observatory will last. "The analysis shows that less propellant than originally planned for is needed to correct Webb's trajectory towards its final orbit," said NASA officials. "Consequently, Webb will have much more than the baseline estimate of propellant – though many factors could ultimately affect Webb's duration of operation."

Webb has completed two of the three burns required to see it to its destination; the final burn will take place nearly a month after launch and will mark the last step in the observatory's perilous deployment process. Webb is destined to orbit a location known as the second Earth-Sun Lagrange point, or L2, which is nearly 1.5 million kilometres (1 million miles) from Earth in the direction opposite the Sun. Here Webb will be less vulnerable to solar radiation that can interfere with its infrared observations.

Lagrange points are sometimes nicknamed 'parking spots' for spacecraft, as they mark locations where the gravitational tugs of different bodies balance out. However, throughout its stay at L2, Webb will need to conduct occasional small thruster burns for station keeping and momentum management to retain its proper location and orientation in space. That's what the propellant remaining after the third burn will be used for. And Webb will have more fuel left in its tank than NASA had dared to hope. The initial launch precisely targeted the observatory's desired trajectory, meaning the spacecraft needed to spend less time and fuel on its first two correction manoeuvres.

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COMETS' HEADS MAY BE GREEN, BUT NEVER THEIR TAILS

Words by Samantha Mathewson

© NASA

Comets, composed of frozen gases, rock and dust, are the leftover remains from the formation of the Solar System about 4.6 billion years ago. The icy bodies heat up very quickly as they approach the Sun in their orbits, causing the solid ice to turn directly into gas via a process called sublimation, which intensifies the bright-green glow. However, the green glow appears only around the head of some comets, but never in the tails trailing behind them. Now scientists from the University of New South Wales (UNSW) Sydney in Australia think they know why.

Using a vacuum chamber and lasers, the researchers were able to recreate the chemical reaction that occurs when ultraviolet radiation from the Sun breaks apart a compound called diatomic carbon, also known as dicarbon or C_2. The reaction causes the icy bodies to appear green. This process, called photodissociation, was originally theorised by physicist Gerhard Herzberg in the 1930s, but has been hard to test until now. Dicarbon is made up of two carbon atoms and is highly reactive and unstable. It's only found in extremely energetic or low-oxygen environments like stars, comets and the interstellar medium. However, on a comet, dicarbon can't exist until the body gets close to the Sun. The Sun heats the comet's organic matter, causing it to evaporate and enter the coma, which is the gassy envelope around the comet. The sunlight then breaks up the larger organic molecules, creating dicarbon.

As a comet gets even closer to the Sun, photodissociation breaks up the fresh dicarbon before it can move very far from the nucleus, or head, of the comet. So while the comet itself appears brighter as it approaches the Sun, the radiant green coma shrinks as the dicarbon is broken up by sunlight. The dicarbon never makes it to the comet's tail, which is why that part of the comet doesn't glow green.

Above: Comet ISON exhibiting a green glow on solar approach

'COSMIC MONSTER' STAR SPITS ENERGY WITH THE FORCE OF A BILLION SUNS

Words by Mindy Weisberger

A dense, magnetic star violently erupted and spat out as much energy as a billion Suns - and it happened in a fraction of a second. This type of star, known as a magnetar, is a neutron star with an exceptionally strong magnetic field, and magnetars often flare spectacularly and without warning. But even though magnetars can be thousands of times brighter than our Sun, their eruptions are so brief and unpredictable that they're challenging for astrophysicists to find and study. However, researchers recently managed to catch one of these flares, calculating oscillations in the brightness of a magnetar as it erupted. The scientists found that the distant magnetar released as much energy as our Sun produces in 100,000 years, and it did so in just one-tenth of a second.

A neutron star forms when a massive star collapses at the end of its life. As the star dies in a supernova, protons and electrons in its core are crushed into a compressed mass that combines intense gravity with high-speed rotation and powerful magnetic forces. The result, a neutron star, is around 1.3 to 2.5 solar masses - one solar mass is the mass of our Sun, or about 330,000 Earths - crammed into a sphere measuring just 12 miles (20 kilometres) in diameter.

Below: These dense objects emit powerful flares across the universe

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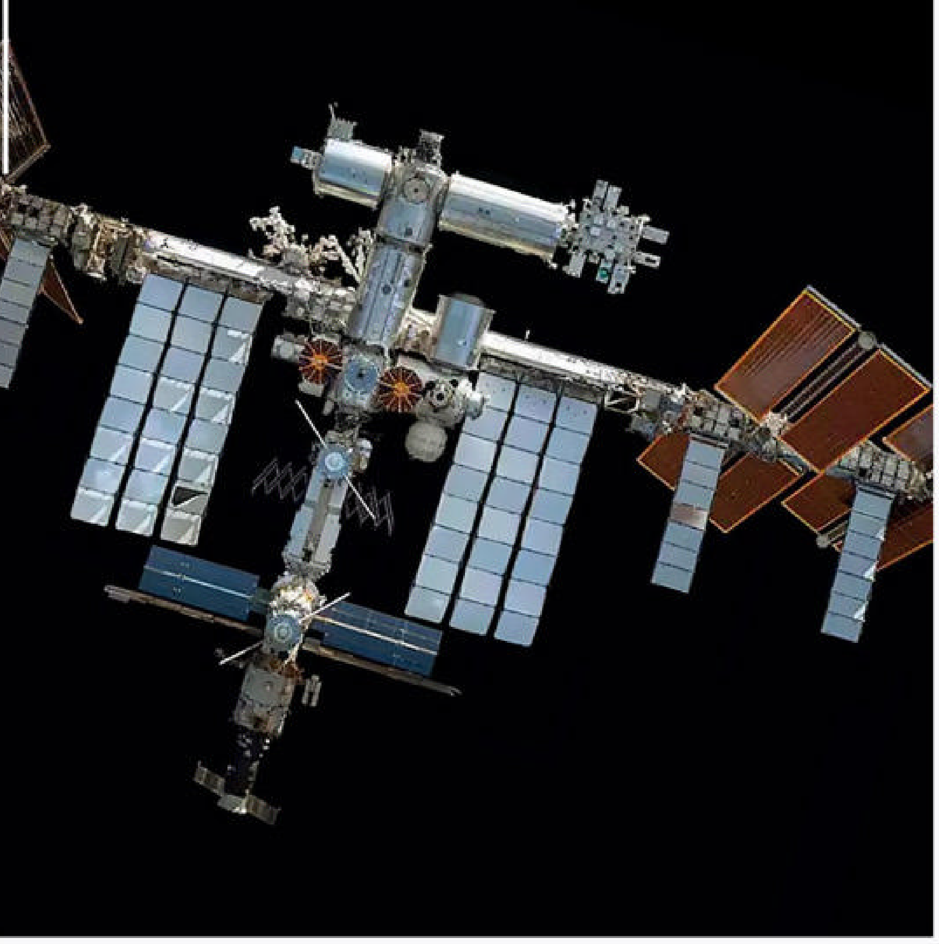
WHITE HOUSE DIRECTS NASA TO EXTEND INTERNATIONAL SPACE STATION OPERATIONS THROUGH 2030

Words by Robert Z. Pearlman



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Above: NASA will continue to operate the ISS for longer than previously intended

NASA administrator Bill Nelson has been directed to work with NASA's partners, including the European Space Agency (ESA), Canadian Space Agency, Japan Aerospace Exploration Agency (JAXA) and Russia's Roscosmos, to enable the ISS' use throughout the rest of this decade. "I'm pleased that the Biden-Harris administration has committed to continuing station operations through 2030," said Nelson. "The ISS is a beacon of peaceful international scientific collaboration and for more than 20 years has returned enormous scientific, educational and technological developments to benefit humanity."

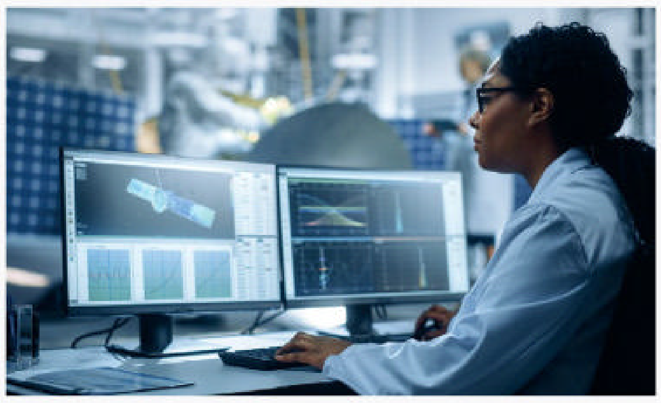
NASA has been seeking ways to hand over its day-to-day operations of the space station to commercial entities in order to free up appropriations for its Artemis program of crewed lunar exploration. "The US' continued participation will enhance innovation and competitiveness, as well as advance the research and technology necessary to send the first woman and first person of colour to the Moon under NASA's Artemis program and pave the way for sending the first humans to Mars," said Nelson.

The extension will also provide more time to ensure a seamless handover of low-Earth orbit research and commercial activities from the ISS to new private outposts. NASA has recently entered into agreements with companies to develop commercial space stations either as free-flying platforms or, as in one case, as a temporary extension to the ISS before separating on its own.

ROCKET SCIENTISTS AREN'T ANY SMARTER THAN THE REST OF US, SCIENCE SAYS

Words by Rebecca Sohn

"It's not rocket science" is an expression used to describe tasks that aren't complicated. But are rocket scientists smarter than everyone else? That was a question researchers sought to answer in a new study in medical journal *BMJ*; the study also applied the analysis to brain surgeons. The study was led by researchers at universities and hospitals in London and Bristol, as well as UK charity Brainbook, which is dedicated to neurosurgical communication and engagement.



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Left: The new study tested the minds of almost 20,000 participants

Researchers gave the Great British Intelligence Test to aerospace engineers and neurosurgeons. The test evaluates areas of cognition like planning and reasoning, working memory, attention and emotional processing. The researchers compared the results of 300 aerospace engineers to those of 72 neurosurgeons from across the UK, Europe, the US and Canada, as well as to the scores of 18,257 members of the British public.

The neurosurgeons scored higher than the aerospace engineers in semantic, or word-based problem solving, while the aerospace engineers scored higher in mental manipulation and attention. There were no other notable differences between their scores. But how did the saying hold up? Compared to the general population, neurosurgeons had faster problem-solving speeds but slower memory recall. There were no notable differences between the scores of aerospace engineers and the general population.

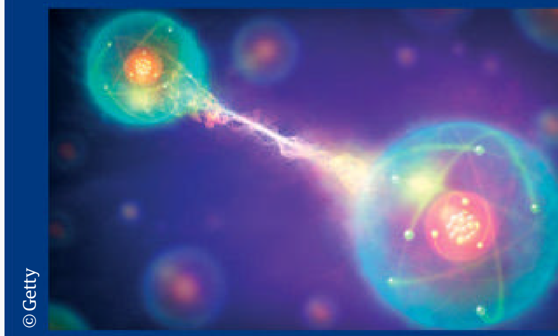
IMAGINARY NUMBERS COULD BE NEEDED TO DESCRIBE REALITY

Words by Ben Turner

Imaginary numbers are what you get when you take the square root of a negative number. When you add imaginary numbers and real numbers, the two form complex numbers, which enable physicists to write out quantum equations in simple terms. But whether quantum theory needs these mathematical chimeras or just uses them as convenient shortcuts has long been controversial.

Even the founders of quantum mechanics thought the implications of having complex numbers in their equations was disquieting. Erwin Schrödinger - the first person to introduce complex numbers into quantum theory - wrote, "What is unpleasant here, and indeed directly to be objected to, is the use of complex numbers." Schrödinger did find ways to express his equation with only real numbers alongside an additional set of rules for how to use the equation.

But now, two studies have proven him wrong. They show if quantum mechanics is correct, imaginary numbers are a necessary part of the mathematics of our universe.



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Right: Schrödinger wasn't a fan of imaginary numbers

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COMPLETE GUIDE TO

EXOPLANETS

OUR KNOWLEDGE OF WORLDS BEYOND THE SOLAR SYSTEM HAS EXPLODED IN THE LAST THREE DECADES

Reported by Robert Lea

© Tobias Roetsch

Ever since humans first discovered that the stars in the night sky were bodies similar to our Sun, we've dreamed and speculated about the worlds that could orbit these stars. Would they be rocky terrestrial planets like Earth? Could they possess liquid water? Could the presence of this vital life-sustaining element on other worlds mean that we are not alone in the universe?

"For millennia, humans have been asking the question of whether we are alone. And tied to that question, are other planets anywhere else?" Nikku Madhusudhan, a professor of astrophysics and exoplanetary science at the Institute of Astronomy of the University of Cambridge, tells **All About Space**. "It's very fundamental to being human to ask the question if there are planets elsewhere."

With this considered, it's almost shocking to think that before the 1990s astronomers weren't even certain that stars outside the Solar System possessed their own planets. There was no evidence to suggest that extrasolar planets, or exoplanets for short, didn't exist, nor were there hints that the Solar System was in any way unique in the Milky Way. But until the very end of the 20th century, astronomers had been frustrated by the lack of direct evidence of worlds beyond the influence of our star.

This is because exoplanets are notoriously difficult to detect. Historically, the most successful exoplanet detection methods have worked by inferring the tiny effects that planets have on their parent stars, like tiny dips in light or the near-imperceptible 'wobble' they cause in their star's motion. "Until 30 years ago, we didn't know of any planets outside the Solar System; all we knew of were the planets in the Solar System," Madhusudhan continues. "But as soon as exoplanets were discovered, that opened an entirely new window into the universe and its other planetary systems."

TYPES OF EXOPLANET

HOT JUPITERS

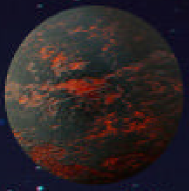
Mass: Up to 12 times Jupiter's mass

Size: 0.3 to 10.0 times Jupiter's radius

Number discovered: 1,458

Gas giants like Jupiter. The difference is these worlds orbit closer to their stars, with short orbits and blistering surface temperatures. WASP-76b is a planet so close to its host that it completes an orbit in under two days.

SUPER-EARTHS



Mass: Up to ten times Earth's mass

Size: Between 0.8 and 4.0 times Earth's radius

Number discovered: 604

Rocky terrestrial worlds or gas planets more massive than Earth but smaller than Neptune. One example of a super-Earth is Gliese 15 A b, a rocky world 11 light years away which is over three times the size of Earth.

SUB-NEPTUNES

Mass: Up to 17 times Earth's mass

Size: Over 2.0 times Earth's Radius

Number discovered: 1,719

Planets similar in size to the Solar System's ice giant Neptune, they're believed to be the most common type of planet in the Milky Way. Discovered in 2018, Kepler-1655 b has a radius around 2.3 times that of Earth, with five times our planet's mass.

TERRESTRIAL

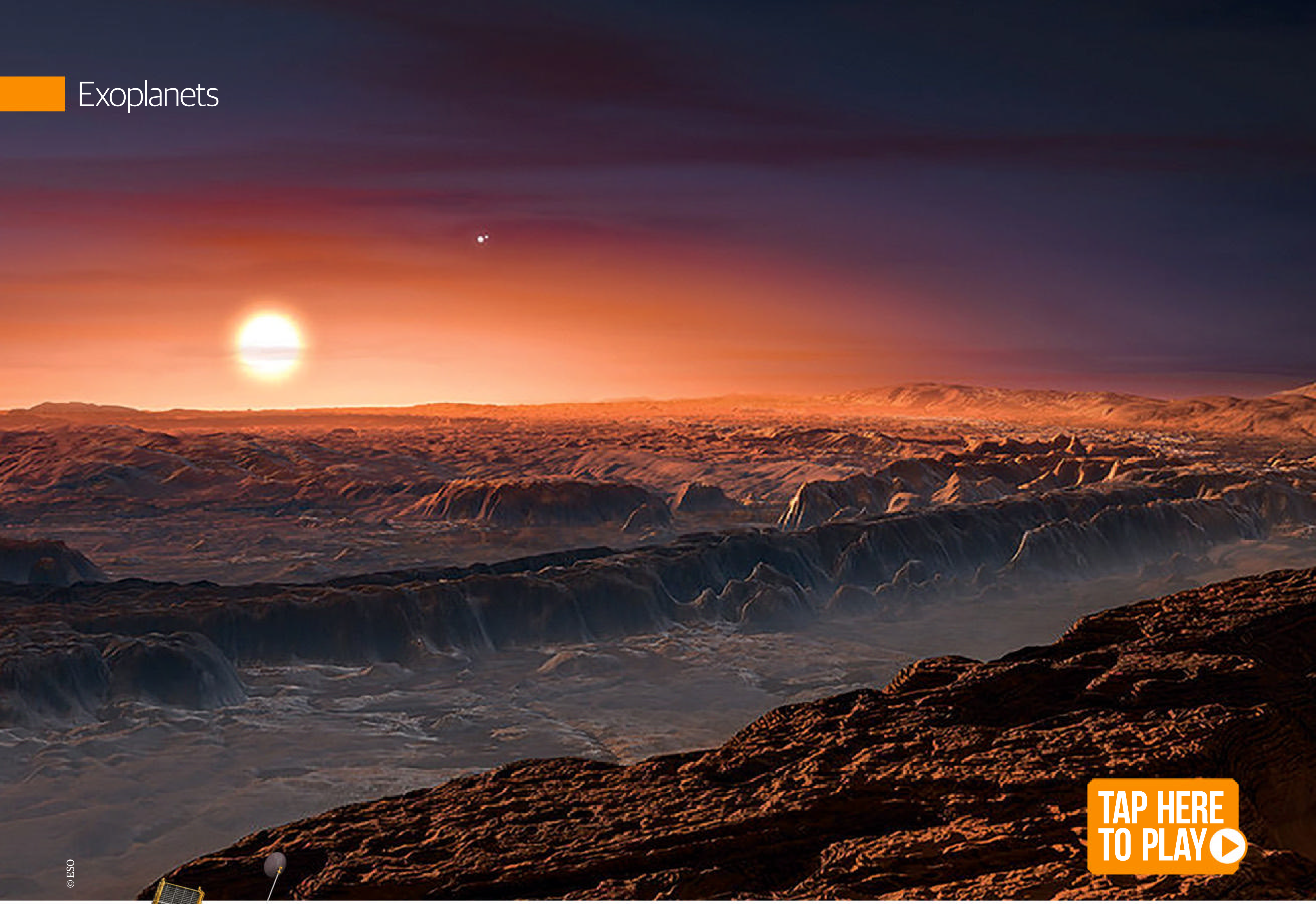
Mass: Around that of Earth

Size: Between 0.5 to 2.0 times Earth's radius

Number discovered: 186

These are small, rocky worlds like the Solar System's inner planets Mercury, Venus, Earth and Mars. TRAPPIST-1e is the fourth planet from its star, 40 light years from Earth. Existing in the habitable zone of its host, it could potentially have liquid water.

AR SCAN CODES FOR MODELS



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Above: Terrestrial planets have rocky surfaces, like Earth

Since this point, improved technology and detection techniques have resulted in a bulging exoplanet catalogue of over 4,800 distant worlds. "The first big milestone in the study of exoplanets was the realisation of just how common they are," adds Madhusudhan, who developed a technique of atmospheric retrieval to infer the compositions of exoplanets. "But also, those exoplanets are extremely diverse. Exoplanets come in all sorts of masses, sizes and temperatures."

When it comes to the categorisation of these objects, humanity's Solar System bias is evident. Worlds outside the Solar System are labelled as super-Earths, hot Jupiters and sub-Neptunes, but these planets can be radically different from those of our system, coming in a vast array of forms.

If anything, the discovery of thousands of exoplanets has shown that our Solar System is reassuringly, and almost uniquely, mundane. And the first exoplanet discovered was an example of an object absent from the Solar System. The first planet detected outside of the Solar System was discovered by Aleksander Wolszczan and Dale Frail in January 1992. The duo discovered the rocky exoplanet orbiting the binary PSR B1620-26, consisting of a white dwarf and a pulsar, located over 12,000 light years away.

The following year, a second planet was discovered in the same system – also a terrestrial world. These planets, the two outermost planets of the system, were given the names Poltergeist and Phobetor and represented the first examples of so-called super-Earths. These planets are defined by their masses, which are greater than our planet's but still less than those of the Solar System's ice giants, Uranus and Neptune. The upper limit for the mass of a super-Earth is generally considered to be about ten times that of our planet. But you shouldn't be fooled into thinking that super-Earths bear any other similarities to our planet. The term doesn't say anything about an exoplanet's surface conditions or habitability. As a striking example of this fact, researchers quickly determined that neither Poltergeist nor Phobetor could support life, as they were being blasted by harsh radiation from the pulsar they orbited.

The search for a planet around a star similar to the Sun hit gold in 1995 when Michel Mayor and his then-doctoral student Didier Queloz discovered 51 Pegasi b, or Dimidium, a planet in orbit around a star that resembled our Sun. In October 2019, the Nobel Committee awarded the Nobel Prize in Physics to the duo for their discovery of the planet. But though the star it

EXOPLANET MISSIONS PAST

THE HUBBLE SPACE TELESCOPE

Launched in 1990, the Hubble Space Telescope has been one of the most influential instruments in the investigation of exoplanets. Hubble was key in the atmospheric investigation of HD 209458 b that revealed water vapour around the gas giant.

orbits, 51 Pegasi, is Sun-like, that doesn't mean its planetary system resembles the Solar System. This discovery marked the first detection of a hot Jupiter - a planet with the size and composition of the Solar System's gas giant, but located scorchingly close to its parent star.

"These planets are at an orbital distance closer than Mercury is from the Sun. That means hot Jupiters complete their orbits in only a few days. Due to their location close to their host stars, they're highly irradiated, with temperatures of 1,725 degrees Celsius (3,140 degrees Fahrenheit) or more," Romain Allart, a Trottier postdoctoral fellow at the University of Montréal, Canada, and a team member at the Institute for Research on Exoplanets, tells **All About Space**.

Not only was 51 Pegasi b an early hint to astronomers that the universe is a wilder and more varied place than they may have previously suspected when it comes to planets, but hot Jupiters would also become mainstays of the exoplanet catalogue. "Hot Jupiters are actually not so common in the universe, but due to instrumental biases they are extremely common in the current exoplanet catalogue," Allart, who was part of the team that investigated the hot Jupiter WASP-76b, explains. "Because they are close, large and massive, the radial velocity and transit techniques are efficient to detect hot Jupiters; these two techniques have discovered almost all exoplanets up until now."

However, in terms of exoplanet populations, Madhusudhan says that sub-Neptunes - planets with a smaller radius than Neptune but a larger mass, or those with a smaller mass than Neptune but a larger radius - seem to dominate the Milky Way. "The realisation that small planets are extremely common elsewhere is another major milestone," Madhusudhan adds.

One milestone in exoplanet research that is currently ongoing and will develop exponentially in the future, the astrophysicist says, is the investigation of these more diminutive planets' atmospheres and the search for water. An exoplanet transiting the face of its host doesn't just provide a great way for astronomers to spot such a world via the dip in light output from the star it causes. The transit method has also proved a good way of assessing the composition of a planet's atmosphere. This is because atoms and molecules absorb light at characteristic wavelengths. By observing the 'gaps' in the light signatures of stars as they shine through planets' atmospheres, astronomers can see what elements make up these gaseous envelopes.

In 1999, Greg Henry and David Charbonneau used the transit method to detect and observe an exoplanet as it passed in front of the star HD 209458, revealing the planet, HD 209458 b, had an atmosphere of oxygen, nitrogen, carbon and, importantly, water. This atmosphere is being stripped away from the world, leaving a trail behind it that is similar to that of a comet.

Madhusudhan points out that since 1999, and particularly in the past decade, atmospheric observations of exoplanets have taken off in a big way, with the first robust measurements of water vapour in the atmospheres of these planets

© NASA

EXOPLANET MISSIONS PRESENT

TESS AND KEPLER

Using the transit method of exoplanet detection, the Transiting Exoplanet Survey Satellite (TESS) is the current gold standard in the search for alien worlds. TESS, launched in 2018, has identified 4,500 potential exoplanets, of which over 150 have been confirmed.

In terms of sheer volume of confirmed exoplanet detections, the Kepler Space Telescope is going to be hard to beat. After its launch in 2009, Kepler spotted at least 4,763 exoplanets, of which 2,703 have been confirmed.

> "IT'S VERY FUNDAMENTAL TO BEING HUMAN TO ASK THE QUESTION IF THERE ARE PLANETS ELSEWHERE"
>
> NIKKU MADHUSUDHAN

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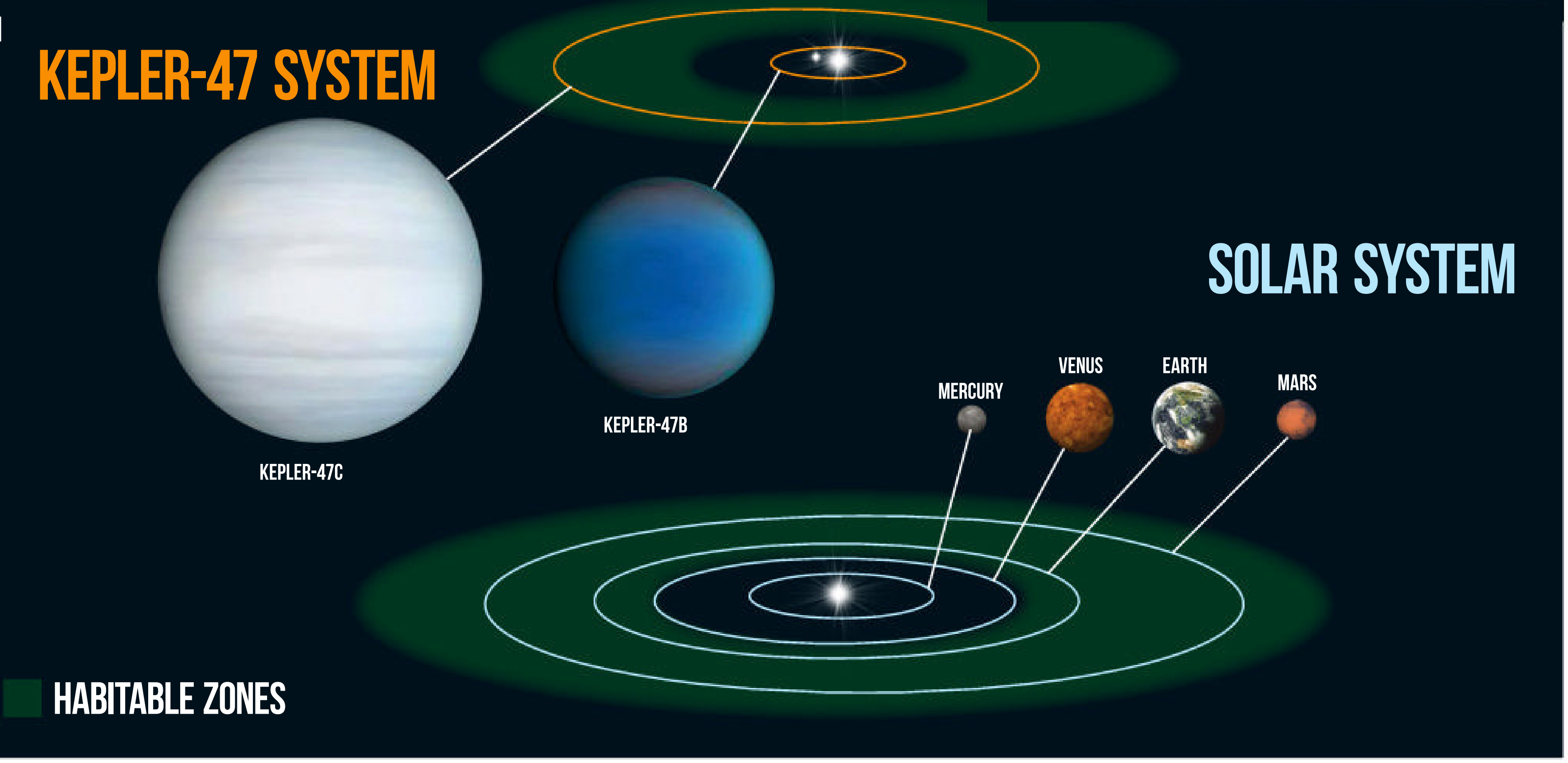

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Right (inset): One goal of exoplanet research is to find a future base for humanity

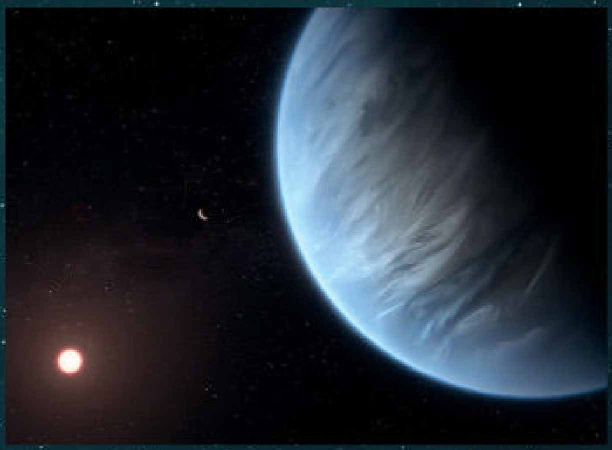
Right: Exoplanets discovered by Kepler orbiting a binary pair, with one in the Goldilocks zone around the stars

FINDING AN EARTH-LIKE PLANET

Is there a planet identical to ours somewhere in the Milky Way?

It's perhaps of little wonder that with our own planetary biases, much of our search for exoplanets has hinged on the search for worlds similar to Earth in both composition and location in the habitable zone of their main sequence stars. Another condition that would make a world similar to Earth would be a magnetic field, which can prevent an atmosphere from being stripped away and thus sustain life.

Several of the planets in the exoplanet catalogue are similar to Earth in a range of ways, be it distance from their star, their mass or their radius. Below are 21 candidates for Earth-analogue worlds. But even if these worlds do fit the description of a 'planet B' that could be occupied by humans in the future, crewed travel to worlds outside the Solar System is thus far unfeasible to say the least, and likely will be for several generations. As Institute for Research on Exoplanets scientist Romain Allart points out, that means despite the wealth of exoplanets discovered, protecting our own world is still of paramount importance.



Right: The exoplanet K2-18b, a super-Earth with water and temperatures that could support life

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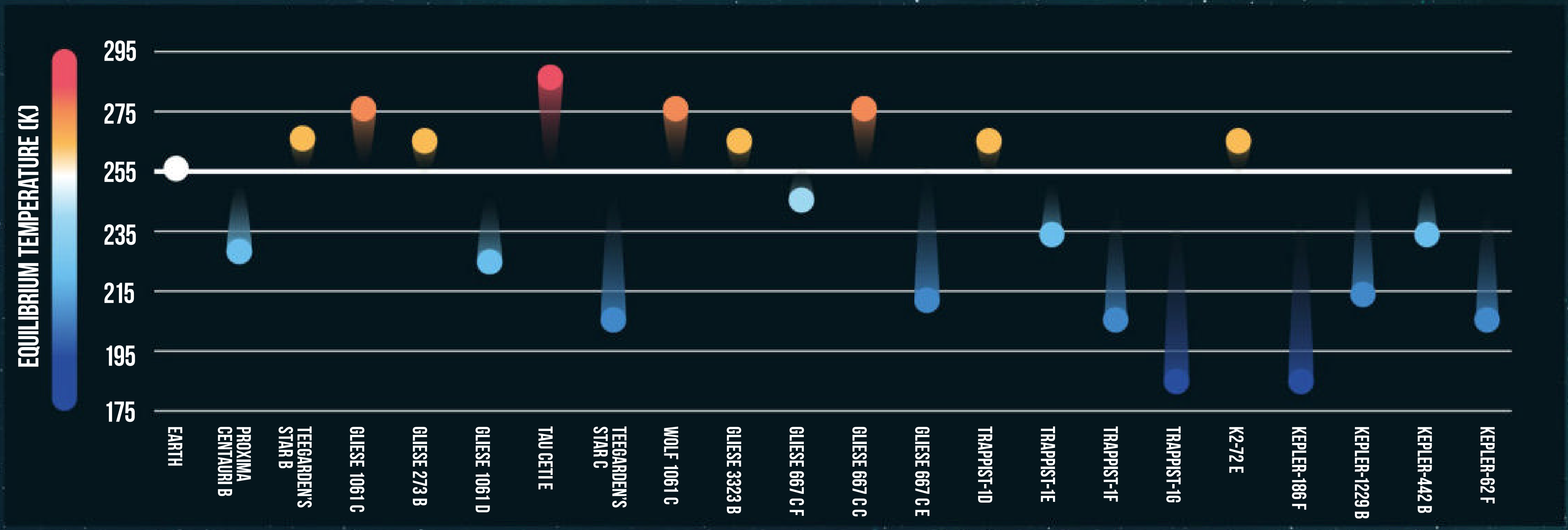
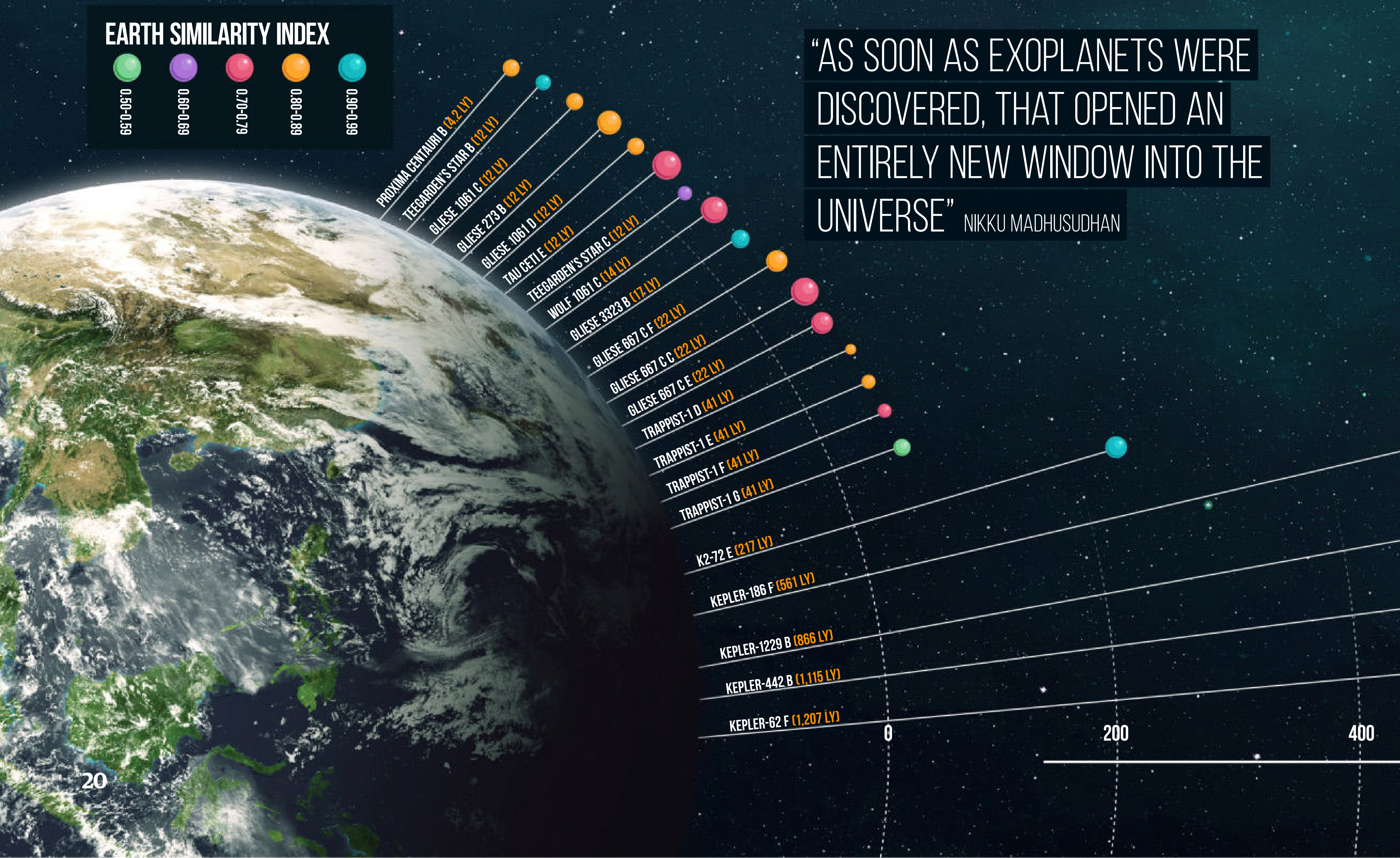


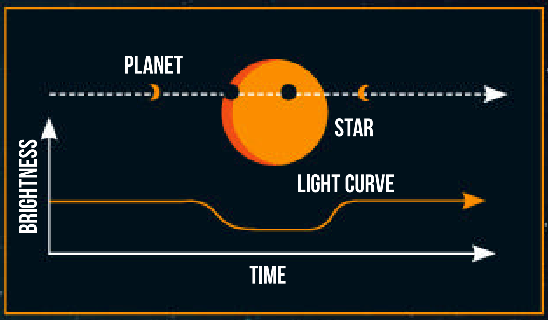


> "AS SOON AS EXOPLANETS WERE DISCOVERED, THAT OPENED AN ENTIRELY NEW WINDOW INTO THE UNIVERSE" NIKKU MADHUSUDHAN

METHODS OF EXOPLANET DETECTION

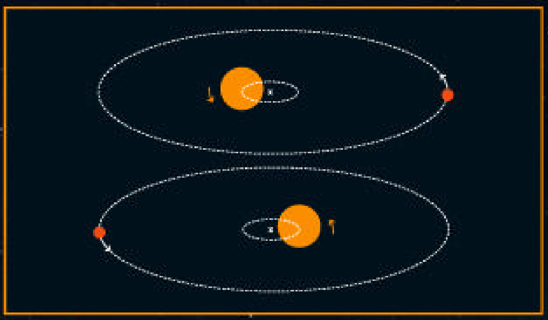
THE TRANSIT METHOD

The transit method hinges on tiny dips in light from a star caused as a planet crosses its face. Despite only being viable for planets that pass between their star and observers, it's delivered over 3,700 exoplanet discoveries.



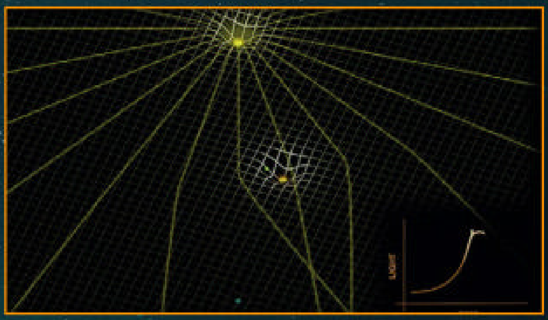
THE RADIAL VELOCITY METHOD

A technique based on the fact that a planet and a star orbit a point of mutual mass, meaning the presence of a planet can be seen as a 'wobble' in the star's motion. Also known as the wobble method, this has delivered around 900 discoveries.



GRAVITATIONAL MICROLENSING

Responsible for the detection of about 130 planets, lensing occurs when objects of tremendous mass warp the fabric of space. By observing the curvature of light from a distant object, details can be ascertained about intervening objects, like planets.



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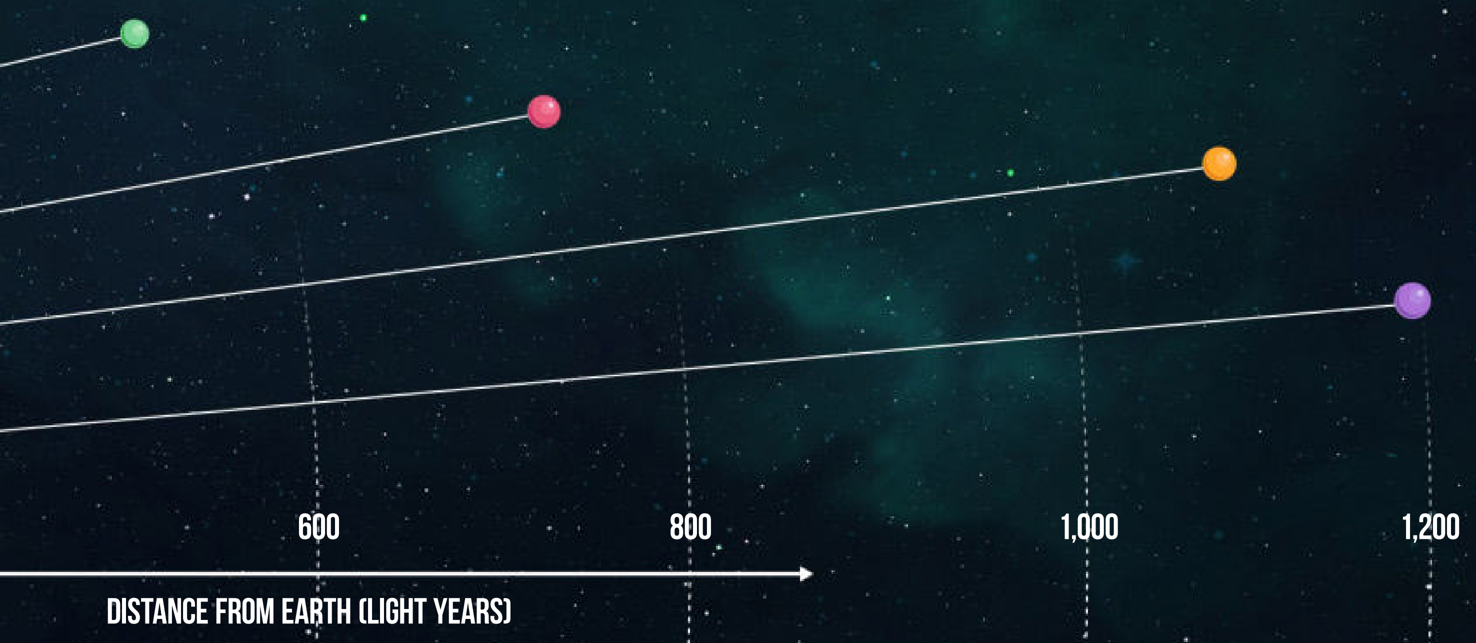
DIRECT IMAGING

Occasionally, by blocking the light from a parent star astronomers can actually directly image an exoplanet. This method has resulted in the discovery of 54 worlds outside the Solar System. This includes TYC 8998-760-1 b and c, pictured below.

© ESO

THE GOLDILOCKS ZONE

Not too hot. Not too cold, but just right. The habitable zone is defined as the region around a star at which liquid water can exist. In the Solar System, Earth exists within the Goldilocks zone, but so do Mars and Venus. This should suggest that just because a planet exists in a habitable zone doesn't mean it will be abundant with water. Other factors are vital to possessing liquid water, such as planet size and temperature. Exoplanets in the habitable zone could have lost their water as a result of a runaway greenhouse effect like Venus, or through the loss of a magnetic field because they were too small to maintain it, as seems to be the case with Mars. But the term is based on our bias. There's only one planet we are aware of that possesses life, and it sits in this zone. Too hot and water boils; if water exists on worlds too close to their star it only does so as vapour. Too cold and liquid water freezes to ice. This may not totally rule out life, however, as liquid water could exist beneath an icy shell. But just right, and liquid water could exist.



made. But unfortunately, as was the case with HD 209458 b, many of these detections, which have become commonplace, tell us little about the possibility of life existing there. "Hot, giant planets are where we have detected water, for the most part as water vapour. And there's no scope of life on these planets," the astrophysicist says.

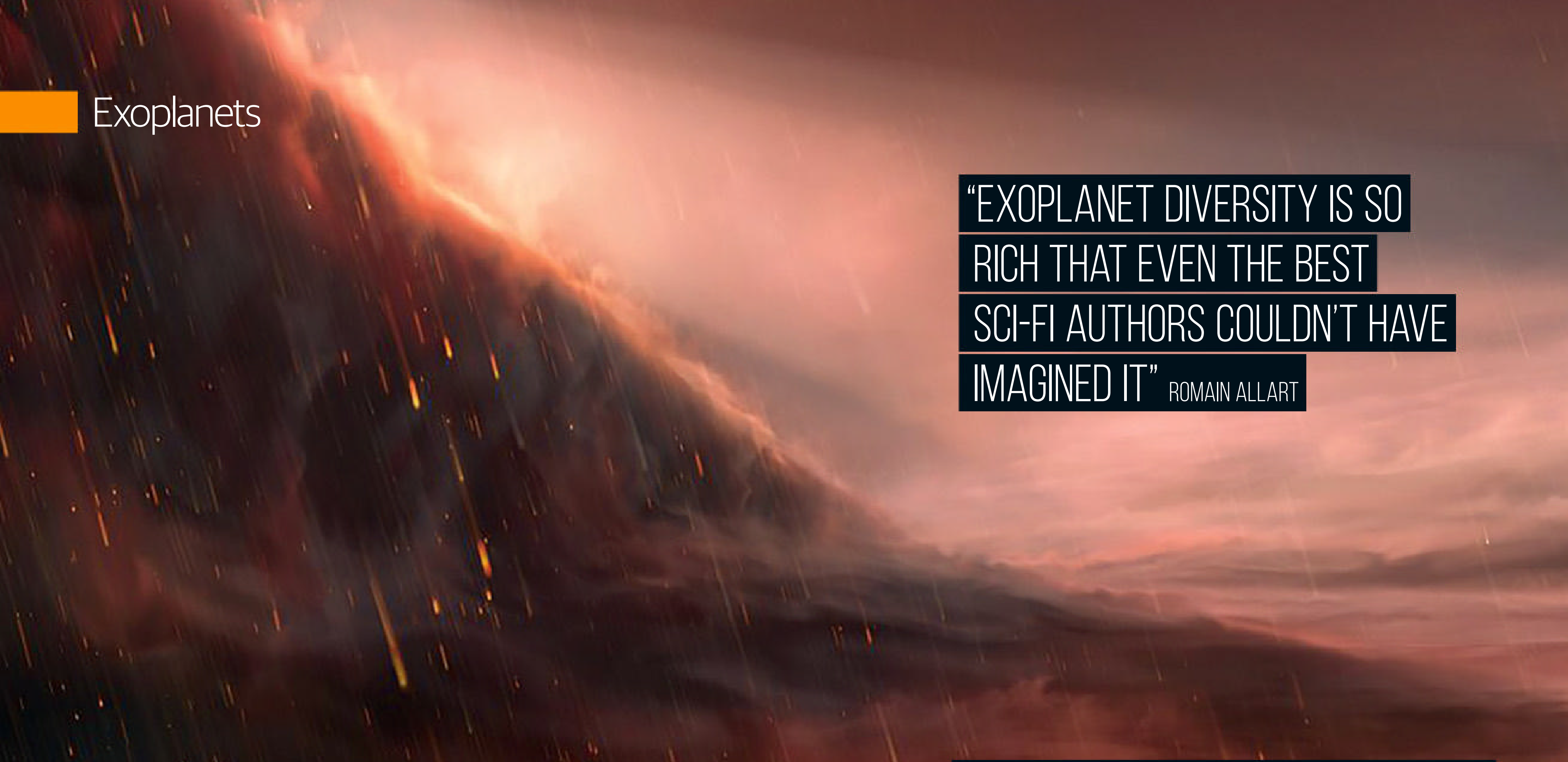
Excitingly, however, this is beginning to change. Madhusudhan, who is the editor of a forthcoming book called *Exofrontiers* which collects pioneering work from the exoplanet science community, points out that our methods of examining atmospheres have improved to the point where we are now able to detect chemical elements around much smaller planets. This includes Earth-like worlds in the habitable zones of planets where conditions are just right to allow for the existence of liquid water. "We are able to detect small Earth-sized planets in the habitable zones of their host stars around nearby stars. And this is especially true for small stars called M dwarfs," Madhusudhan says, referencing the planets in the TRAPPIST-1 system in particular.

Discovered in 2017 and located just 40 million light years away, the system contains at least seven rocky terrestrial worlds, all of which exist at a suitable distance from their red dwarf to facilitate the existence of water on their surface. "These are all small, rocky, Earth-like planets at the right distances for habitability around their host stars," Madhusudhan says. Observations of the TRAPPIST-1 planets conducted in February 2018 revealed that some of them may even be able to harbour more liquid water and wider oceans than Earth. This makes the system one of the prime targets for atmospheric investigations by future telescopes, including the James Webb Space Telescope (JWST) currently on its way to orbit.

This life-searching, atmosphere-investigating aspect wasn't part of the JWST's mission when the plans for a ten-metre (32.8-foot) passively cooled near-infrared telescope in a high-Earth orbit were initially floated in 1989. In the last year of the 1980s, astronomers hadn't even discovered planets around other stars, and the Hubble Space Telescope, which would make an important contribution to this search, was still a year from launch.

Various teams of astronomers are currently applying for observation time with the new space telescope so they can investigate planets outside the Solar System. This includes Madhusudhan, who will be leading a team working with the JWST to investigate exoplanet atmospheres in unprecedented detail.

"We are indeed in the golden age of exoplanet science, but we are also on the verge of a major revolution in modern astronomy," the astrophysicist says. And while even Webb still



> “EXOPLANET DIVERSITY IS SO RICH THAT EVEN THE BEST SCI-FI AUTHORS COULDN’T HAVE IMAGINED IT” ROMAIN ALLART

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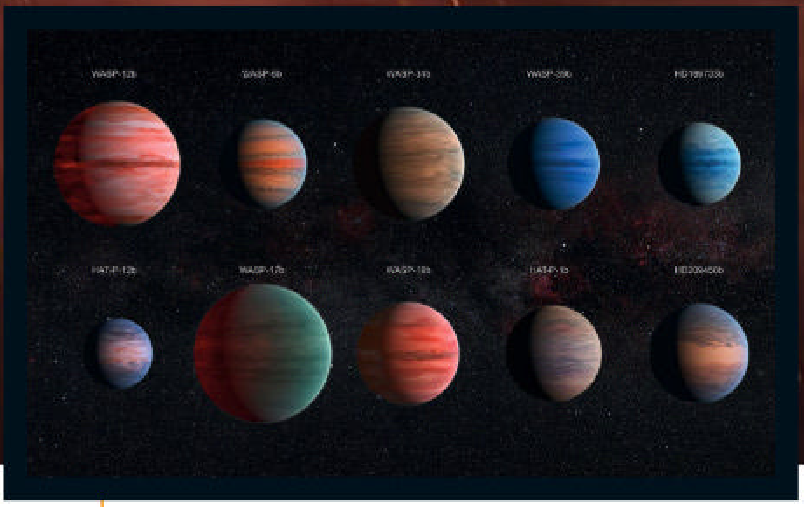

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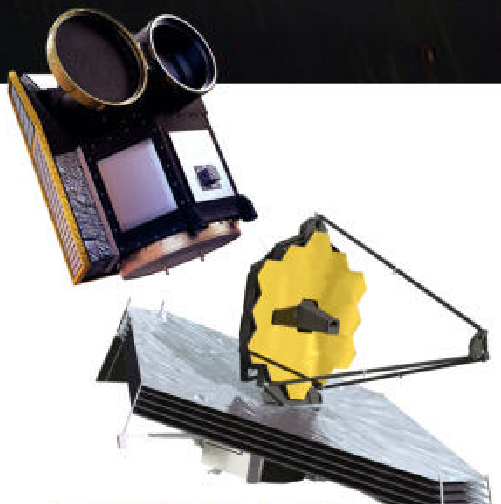
Above: WASP-76b has such a blistering temperature that molten iron rains down on the planet’s cooler side

Above (inset): Hot Jupiters come in a wide variety of shapes and sizes and are easy to detect because they transit their stars often



EXOPLANET MISSIONS FUTURE

CHEOPS AND WEBB

Launched in 2019, the CHaracterising ExOPlanets Satellite (CHEOPS) is the first mission dedicated solely to the investigation of exoplanet atmospheres. CHEOPS will select so-called ‘golden targets’ for follow-up investigations by the James Webb Space Telescope. One of the primary missions of Webb, the most powerful telescope ever launched into space, will be the investigation of the atmospheres of exoplanets. It’s poised to reveal more about distant worlds than any mission that came before it.

won’t be able to conclusively tell if a planet is hosting life, its observing power brings humanity tantalisingly close to the detection of molecules that hint at the presence of living organisms. This will lay further groundwork for future missions. “We are the fortunate generation that might witness the discovery of life elsewhere,” Madhusudhan says. “We have been dreaming of that for thousands of years, and we happen to be that blink-of-an-eye generation in which that momentous discovery is going to happen. To me that is huge.”

Not only this, but Madhusudhan is researching so-called Hycean worlds: water-rich planets with surfaces covered almost entirely in oceans and with atmospheres made up of mostly molecular hydrogen. These hypothetical worlds could potentially redefine the limits of what we consider the habitable zone. This gives researchers targets outside the traditional habitable zone to include in the search for the telltale signatures of life.

And nothing says ‘casting a wider net’ like the revelation last year that astronomers may have caught a hint of the first exoplanet ever to be detected outside of the Milky Way. The team, including Nia Imara from the University of California, may have detected a Saturn-sized exoplanet 28 million light years from Earth in the galaxy Messier 51. This extragalactic exoplanet seems to be orbiting a high-mass compact object such as a neutron star or a black hole.

“Surprisingly, we are only scratching the surface, as we now think that almost one star in every two hosts a planet, and there are hundreds of billions of stars in our galaxy alone, and there are billions of galaxies in the universe,” Allart says. “Exoplanet diversity is already so rich that even the best sci-fi authors couldn’t have imagined it. It’s amazing to discover more and more strange exoplanet systems and worlds.”

Allart continues by explaining that despite this wealth of planets, and our increasing knowledge about them, protecting our own world is still of paramount importance. “The Solar System, and in particular Earth, remains unique in the diversity of exoplanets. Therefore it’s important to understand that there’s no planet B,” he concludes.

Robert Lea
Space science writer
Rob is a science writer with a degree in physics and astronomy. He specialises in physics, astronomy, astrophysics and quantum physics.

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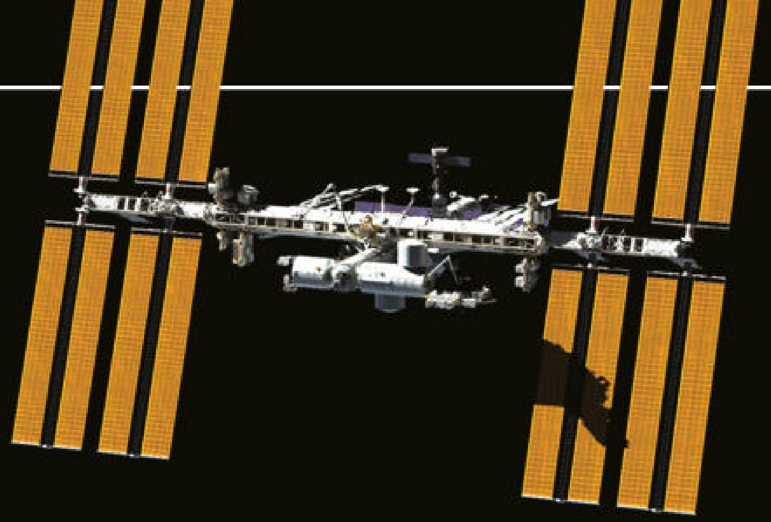


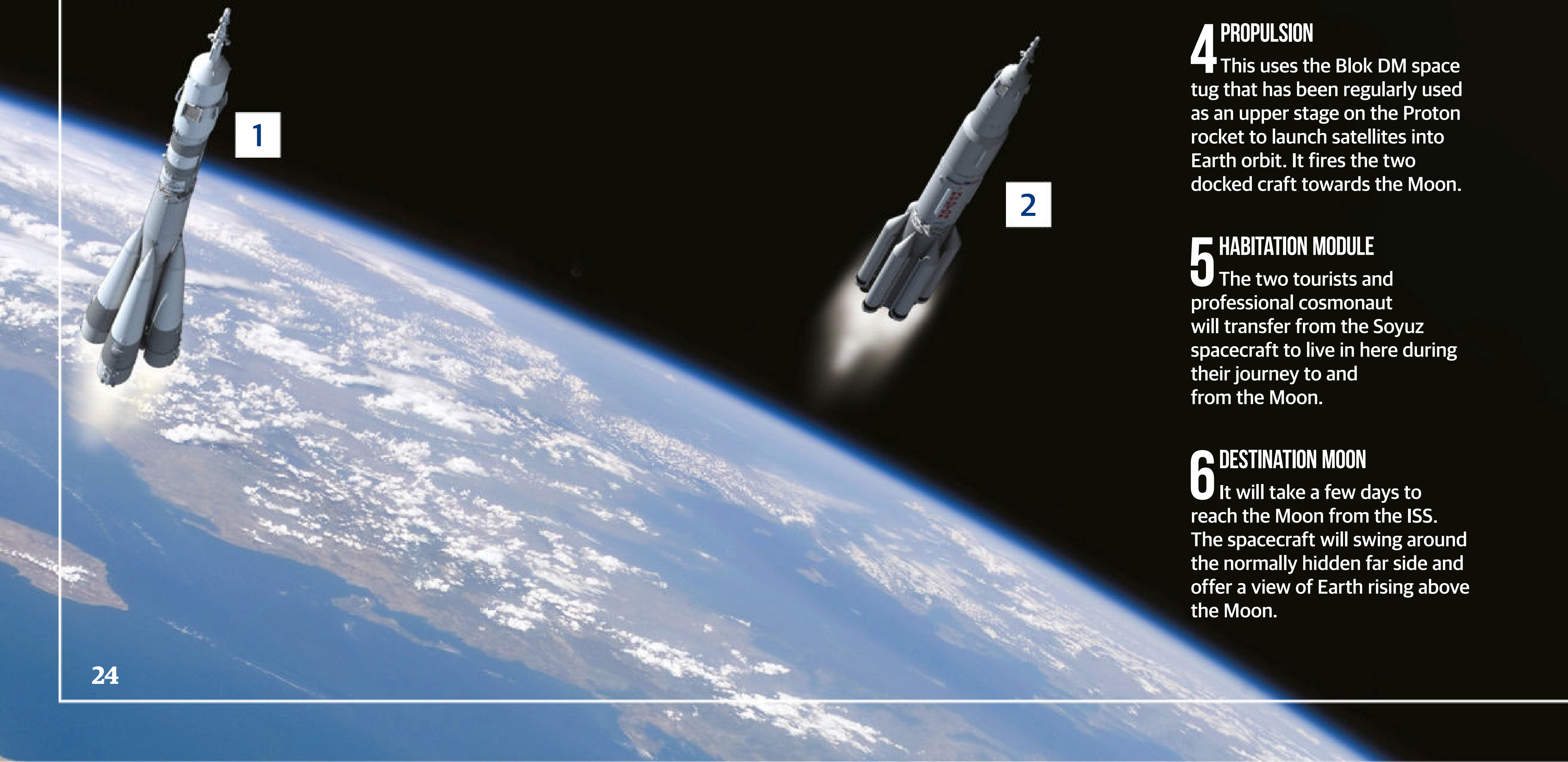
MILLIONAIRE MOON TOURISM

Fancy a trip around the Moon? That's what Space Adventures is offering to anyone able to afford the multimillion-dollar price tag

Multimillionaires and billionaires can book their future flight around the Moon using Space Adventures' imaginative use of existing spacecraft and technology. An essential cornerstone of this project are Soyuz rockets – spacecraft that were originally designed to take cosmonauts to the Moon. They didn't achieve that goal, but in the 1960s and 1970s they were easily adapted to ferry cosmonauts and astronauts into Earth orbit and to space stations. In the decades since the demise of the Space Shuttle, the Soyuz craft has become the world's safest spacecraft, making many trips.

Each trip to the Moon will carry two tourists, who will spend at least eight months preparing themselves for the high g-forces of liftoff and the weightlessness of space, along with training in operating the Soyuz module, collecting data and conducting experiments. They will blast off from Baikonur Cosmodrome in Kazakhstan and dock with the ISS, where they will stay for ten days. While there, they will become acclimatised to living in space, carrying out a few observations and experiments. Meanwhile, a Proton rocket will blast off from Earth to deliver a lunar module into low-Earth orbit. This unmanned craft will consist of a living module and a Blok DM propulsion stage.

The Proton rocket and Blok DM are other blasts from the Soviet past. The Proton rocket was originally designed as an intercontinental ballistic missile, but the plans changed in the hope that it could be used to send cosmonauts



1 SOYUZ ORBITAL MODULE

This carries equipment and provides basic living quarters. A docking mechanism and transfer hatch enable it to be connected to the ISS and lunar module.

2 SERVICE MODULE

This carries oxygen tanks, power, navigation and propulsion systems. It features control thrusters to carry out docking manoeuvres.

3 DESCENT MODULE

The three occupants sit inside this module during launch and re-entry. For this mission, the heat shield will be upgraded.

4 PROPULSION

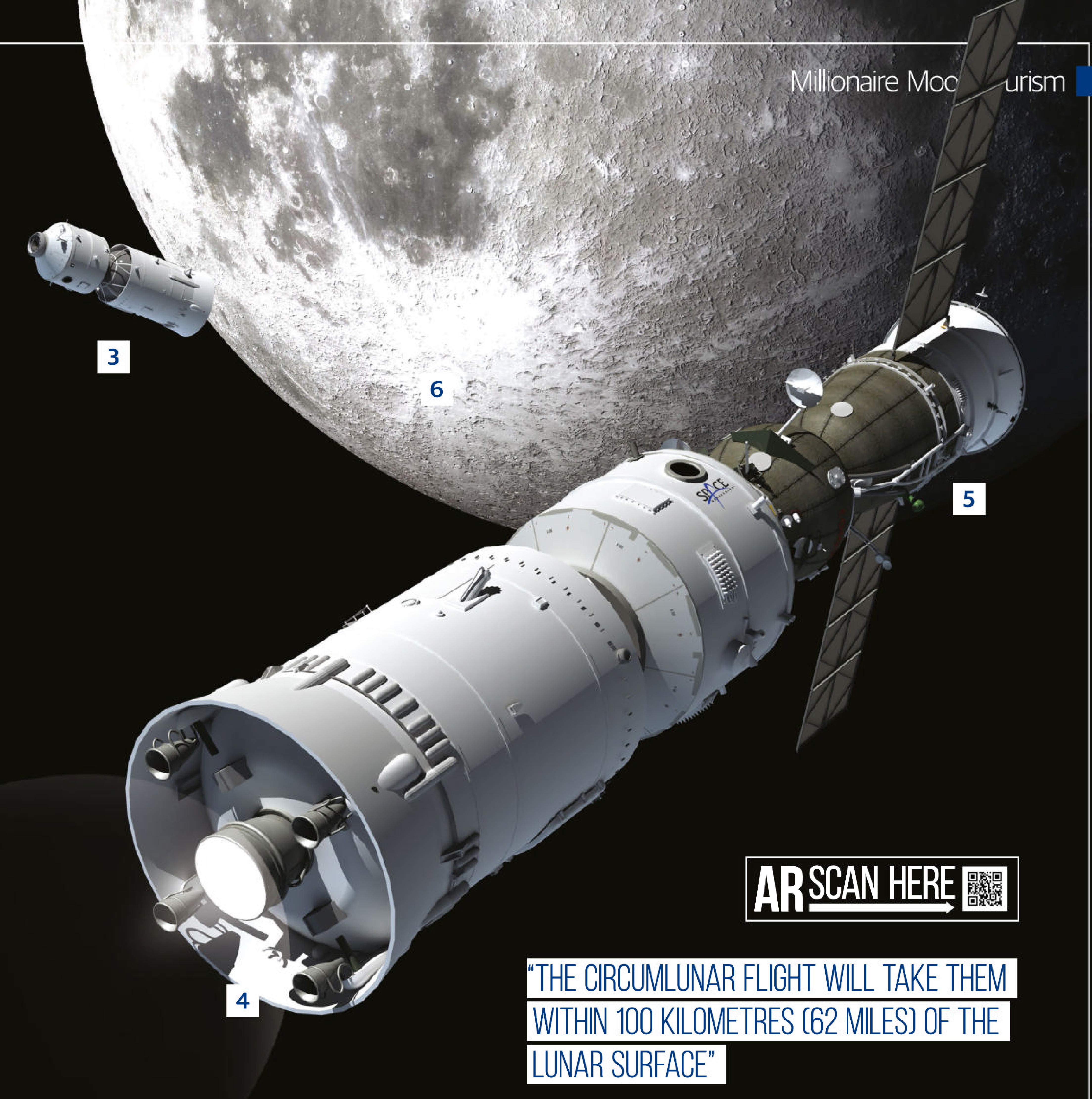
This uses the Blok DM space tug that has been regularly used as an upper stage on the Proton rocket to launch satellites into Earth orbit. It fires the two docked craft towards the Moon.

5 HABITATION MODULE

The two tourists and professional cosmonaut will transfer from the Soyuz spacecraft to live in here during their journey to and from the Moon.

6 DESTINATION MOON

It will take a few days to reach the Moon from the ISS. The spacecraft will swing around the normally hidden far side and offer a view of Earth rising above the Moon.



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> "THE CIRCUMLUNAR FLIGHT WILL TAKE THEM WITHIN 100 KILOMETRES (62 MILES) OF THE LUNAR SURFACE"

around the Moon before the Apollo program. Since then it has been regularly used to launch satellites into Earth orbit.

The Blok DM was developed as the upper stage for rockets taking unmanned craft to the Moon. The 5.5-metre (18-foot) long, four-metre (13-foot) diameter space tug has a main engine that can be fired several times over a multi-day mission. It has been successfully used with the Proton rocket to send unmanned craft to the Moon, Mars and Venus.

The Soyuz itself consists of three modules: a spherical living module at the front, an aerodynamically shaped re-entry module and a service module that carries the main engine, fuel tanks and solar panels. Only the re-entry module will return to Earth.

Once the lunar module is safely in orbit, the tourists, along with a professional Russian cosmonaut, will re-enter the Soyuz spacecraft. They will then leave the trusty ISS to rendezvous and dock with the lunar module. The module will provide far better living quarters than the Soyuz, with much more space, and the Blok DM engine will send the two docked craft in a trajectory around the Moon and back to Earth.

The circumlunar flight will take them within 100 kilometres (62 miles) of the lunar surface, and they will enjoy the sight of the normally hidden far side of the Moon. They will also get a spectacular view of planet Earth rising above the surface of the Moon. This part of their space vacation will last six days, culminating with jettisoning the lunar module and returning to Earth inside the Soyuz spacecraft. The Soyuz capsule's communication and navigation systems will be upgraded, and it will need a different heat shield, as the craft will re-enter the Earth's atmosphere at a greater speed than if it was merely returning from Earth orbit. By skipping the Soyuz through the atmosphere, it will slow enough for it to make a parachute landing to the ground. If there is sufficient demand, Space Adventures will launch a series of tourism expeditions to the Moon.

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INTERVIEW

BIO

Matt Ondler

Private companies are getting ready to take the baton from the International Space Station (ISS). NASA is awarding $415 million (£306 million) to help get three commercial outposts off the ground. Those stations are being developed by teams led by Blue Origin, Nanoracks and Northrop Grumman. In 2020, Houston-based Axiom Space got a NASA contract to deliver at least one habitable private module to the ISS. Axiom plans to launch its first element to the orbiting lab in late 2024, then send several more up over the next few years. Eventually, the connected Axiom modules will detach from the ISS. Axiom's chief technology officer Matt Ondler discusses the company's space station plans, the outlook for private industry in low-Earth orbit and the importance of commercial missions, such as SpaceX's recent Inspiration4 crewed orbital flight.

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MATT ONDLER

“WE WILL SEE IDEAS AND PRODUCTS WE CAN'T IMAGINE TODAY”

Axiom Space's chief technology officer Matt Ondler on life after the International Space Station

Interviewed by Mike Wall

How quickly can humanity get another low-Earth orbit (LEO) station up and running post-International Space Station? Are we likely to see a gap between the ISS' retirement and a new station coming online?
Axiom Space is on schedule to deliver our first privately developed module of the Axiom Station to the ISS in September 2024. We will deliver three additional modules by the end of 2027 to complete our initial space station. With the delivery of the fourth module, Axiom Station will have the capability to be independent of the ISS and can then separate to become an independent next-generation space station with upgraded crew quarters, increased payload capacity and a dedicated manufacturing and research lab module.

This timeline supports the current planned end of the ISS' life, so there should be a seamless transition with no gaps in human continuous presence in LEO. This approach was built from the wealth of ISS and human spaceflight experience at the core of our team.

Broadly speaking, what will our post-ISS LEO presence look like? Will it be mostly privately run stations, or a mix of public and private outposts?
Most will be privately owned and operated stations that support a mixed use of private, commercial and government users. At Axiom, we will provide capability and infrastructure for commercial customers as well as the opportunity for NASA and other government space agencies to continue their research, technology development and national astronaut missions in LEO. A commercial space station provides opportunities for new and non-traditional users of microgravity to engage in research, product development and scaling of manufacturing that we believe has the potential to radically improve life on Earth. A commercial space station also offers cost-saving opportunities for agencies like NASA to conduct fundamental space science research and prepare astronauts for longer missions to the Moon, and on to Mars, without the financial burden of maintaining a LEO station.

Do you see a lot of opportunity for international cooperation on these stations?
The Axiom Station is designed and intended to be an international destination for a wide range of customers – a true global user base, both commercial and governmental, with greater ease of access compared to the ISS today. Moreover, some of our suppliers are already international. Thales Alenia Space in Italy is providing the primary structure for the first two Axiom modules, for example.

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> “AXIOM STATION WILL HAVE THE CAPABILITY TO BE INDEPENDENT OF THE ISS”

© NASA/SpaceX

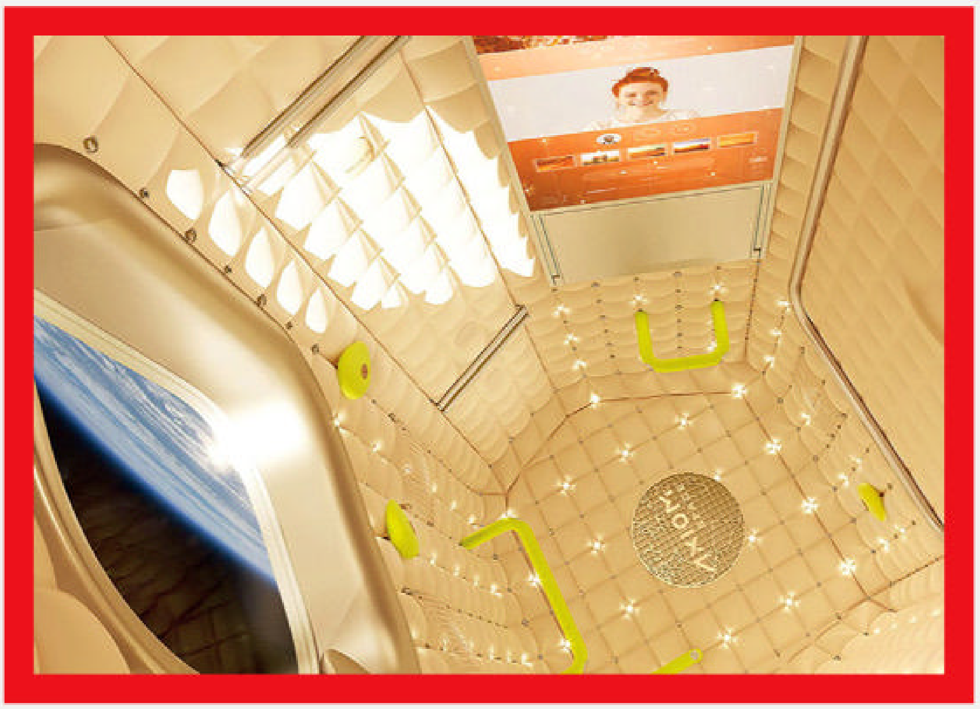
Above: Axiom plans to build the world’s first free-flying commercial space station

Left: SpaceX’s Dragon has been a huge step in commercial spaceflight

Many countries don’t participate in the ISS but have aspirations to be part of the space ecosystem; many of them are already expressing interest in Axiom Station, seeing opportunities to participate in the LEO economy in ways previously not available to them. We are keen to support that and help grow the community of nations that will conduct and lead the next stages of human space exploration beyond LEO.

What are the main industries that you foresee supporting private outposts? Will tourism and pharmaceutical research be big drivers?
Private and national astronauts will certainly be an early and ongoing market, as well as providing a LEO destination that can support research and technology development for further space exploration. But, ultimately, we believe the long-term big driver will be in-space manufacturing. I believe that 15 to 20 years from now we will be surrounded by objects without which we can’t imagine living, and which were manufactured in space.

Objects and products that were manufactured in the unique microgravity environment could disrupt a number of industries. We already see hints at what some of those products might be, but having a commercially available LEO destination will bring out ideas and possibilities that we can’t imagine now. The ISS and NASA couldn’t provide companies opportunities to manufacture at scale. On the ISS, a company could only fly an experiment; even if the experiment was successful, there wasn’t a place for that company to go to make the product at scale. A commercial space station like Axiom’s will provide that opportunity,



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Above: Philippe Starck's vision of the Axiom's habitation module

and therefore I believe we will see all sorts of ideas and products we can't imagine today.

Is the necessary transportation infrastructure already in place – with SpaceX flying people now and Boeing getting ready to – or do we need more crewed vehicles?
Our partners at SpaceX are certainly the current leaders in enabling the new space era through making commercial transportation available. However, transportation to space remains enormously expensive and time-consuming to schedule and plan. More transportation capability can only support the growing space economy and help manage costs. Among some extant needs are low-cost entry vehicles that can return these amazing products we will manufacture in space.

How important are early private missions like Inspiration4 in paving the way for commercial space stations?
All early private human spaceflight missions are important to raise awareness across the stakeholders that can enable or slow the growth of the space economy. Those stakeholders include investors, companies with ideas, engineers and government administrators. Early private missions get investors excited about the market potential, stimulate ideas for commercial applications, spur engineers to join new space startups like Axiom Space and influence government administrators to invest in helping commercial space to succeed.

When it comes to Axiom's private missions to the International Space Station, of which Ax-1 is the first, they are particularly important as a demonstration of the viability of the microgravity platform for new and non-traditional users. These missions are intended to take a mission profile previously only reserved for governments – on board the ISS, participating in robust research programs – and make them available to an expanded user base. A private focus on serious life and work in orbit is a first step in expanding the long-term human presence and capability in space, growing and serving demand for such missions and clearing the way for the launch and operation of Axiom Station.

AXIOM SPACE NEWS

NASA approves the private company's second private mission to the International Space Station

NASA has given the go-ahead to another private crewed mission to the ISS. The agency will work with Axiom Space to find a window for the company's second ISS mission. That flight, known as Ax-2, is currently scheduled to launch from Kennedy Space Center in Florida between autumn 2022 and spring 2023. Axiom has contracted with SpaceX to launch four crewed missions to the ISS using Crew Dragon capsules and Falcon 9 rockets. The first of those flights, Ax-1, is scheduled to launch on 21 February 2022. It will be commanded by Michael López-Alegria, a former NASA astronaut who now works at Axiom. He will be joined by three space tourists, who each reportedly paid $55 million (£41 million) to be part of the eight-day mission.

Ax-2 will last no more than 14 days and will be commanded by Peggy Whitson, a record-setting former NASA astronaut and current Axiom employee. One of her three crewmates will be auto racer, pilot and investor John Shoffner. The identity of the other two crew members has not yet been disclosed. All names are provisional at the moment, however, because NASA has a say in personnel selections. The proposed Ax-1 crewmates are "still completing final evaluations by NASA and its international partners," said the agency.

NASA and Axiom agreed to terms for the Ax-1 mission last May. Ax-2 is the first of two additional private crewed missions to the ISS that NASA plans to select based on a call for proposals issued in June. "Enabling private astronaut missions to the International Space Station is part of the agency's goal to develop a robust low-Earth orbit economy where NASA is one of many customers and the private sector leads the way," said NASA officials "This strategy will provide services the government needs at a lower cost, enabling the agency to focus on its Artemis missions to the Moon and on to Mars while continuing to use low-Earth orbit as a training and proving ground for those deep-space missions."

NASA hasn't yet selected the second of the two planned missions described in the June announcement, which stipulated that flights must be brokered by American organisations and travel on American spacecraft. "NASA will gather lessons learned from the first private astronaut flight as well as other applicable station activities and announce a new flight opportunity in the future," said the agency.

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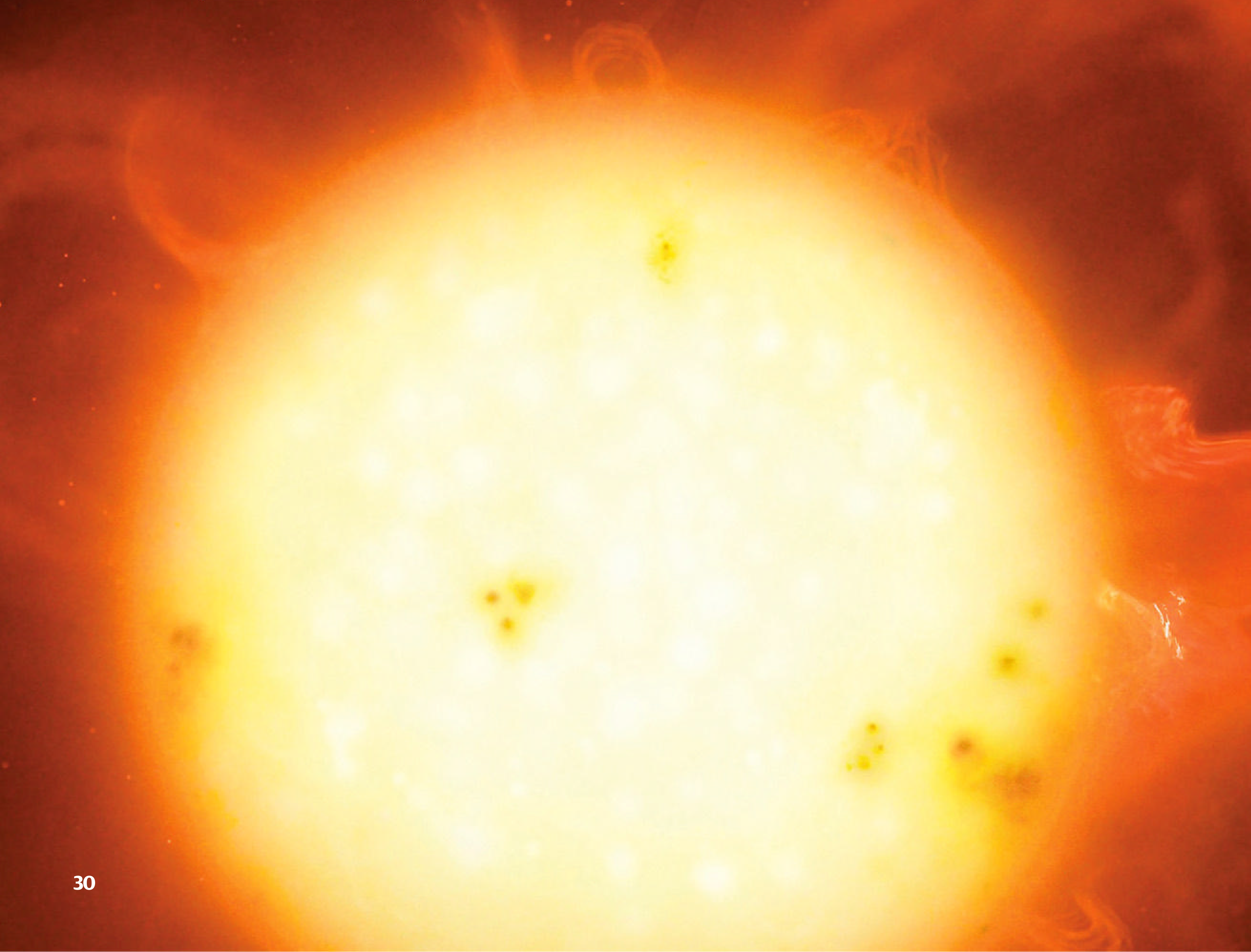
ERUPTION SEEN ON ALIEN STAR FOR FIRST TIME

The outburst is about ten times more powerful than anything similar seen from our Sun

Reported by Charles Q. Choi



Astronomers may have detected a Sun-like star erupting, spotting a giant outburst ten times larger than anything similar ever seen from our Sun. The new results may shed light on the effects such powerful outbursts may have had on the early Earth when life was born, and could have on modern Earth and society.

Our Sun often unleashes flares that can each pack as much energy as millions of hydrogen bombs exploding at the same time. Solar flares are often accompanied by giant, bright tendrils of solar plasma known as filaments, which can unleash magnetic bubbles of superhot plasma called coronal mass ejections that hurtle through space at very high speeds.

When coronal mass ejections hit Earth, they can fry satellites in orbit and trigger major disturbances, known as geomagnetic storms, that can wreak havoc on electrical grids. In 1989, a coronal mass ejection blacked out the entire Canadian province of Quebec within seconds, damaging transformers as far away as New Jersey and nearly shutting down US power grids from the mid-Atlantic through the Pacific Northwest. “Coronal mass ejections can have a serious impact on Earth and human society,” said Yuta Notsu, an astrophysicist at the University of Colorado Boulder.

Previous research found that distant yellow dwarf stars could erupt with ‘superflares’, outbursts packing ten times more energy than the largest known solar flares. Superflares could theoretically blast out equally super coronal mass ejections, but until now astronomers had not seen any evidence that was true. “Coronal mass ejections are the most important aspect when it comes to considering the effects of superflares on planets, especially our Earth,” Notsu said.

In a new study, researchers analysed EK Draconis, a star located about 111 light years from Earth. EK Draconis is a yellow dwarf like the Sun, but is much younger at only 50 million to 125 million years old. “It’s what our Sun looked like 4.5 billion years ago,” said Notsu.

Prior work found that EK Draconis often erupted with flares, suggesting that astronomers monitoring it could get lucky in the hunt for superflares and giant coronal mass ejections. In the new study, the scientists observed EK Draconis from January to April 2020 using NASA’s Transiting Exoplanet Survey Satellite, Kyoto University’s Seimei Telescope and the Nishi-Harima Astronomical Observatory’s Nayuta Telescope.

On 5 April 2020, the research team’s hunch paid off: the scientists detected a superflare that was followed about 30 minutes later by what appeared to be a coronal mass ejection moving at about 1.8 million kilometres (1.1 million miles) per hour. They estimated its mass to be ten times bigger than that of the largest known solar coronal mass ejection. “This is the first detection of a possible coronal mass ejection from a solar-type star,” said Notsu.

Notsu noted that the team was only able to catch the initial phase of the coronal mass ejection, so it remains uncertain whether it fell back onto the star or got ejected into space. Future research should employ a range of telescopes in order to investigate the later phases of coronal mass ejections around other stars, he added.

These findings suggest that the young Sun may have also blasted out giant coronal mass ejections that could in turn have influenced the early Earth. “In other words, coronal mass ejections may be strongly related with the environment where life was born,” said Notsu.

Notsu noted that superflares on our Sun do appear rare. Still, data from tree rings and other sources suggest the Sun may have hit Earth with superflares multiple times in the past 10,000 years. “Discussions over the possibilities and effects of superflares and super coronal mass ejections on our society are important,” he said.

<<ORPHAN

© Getty

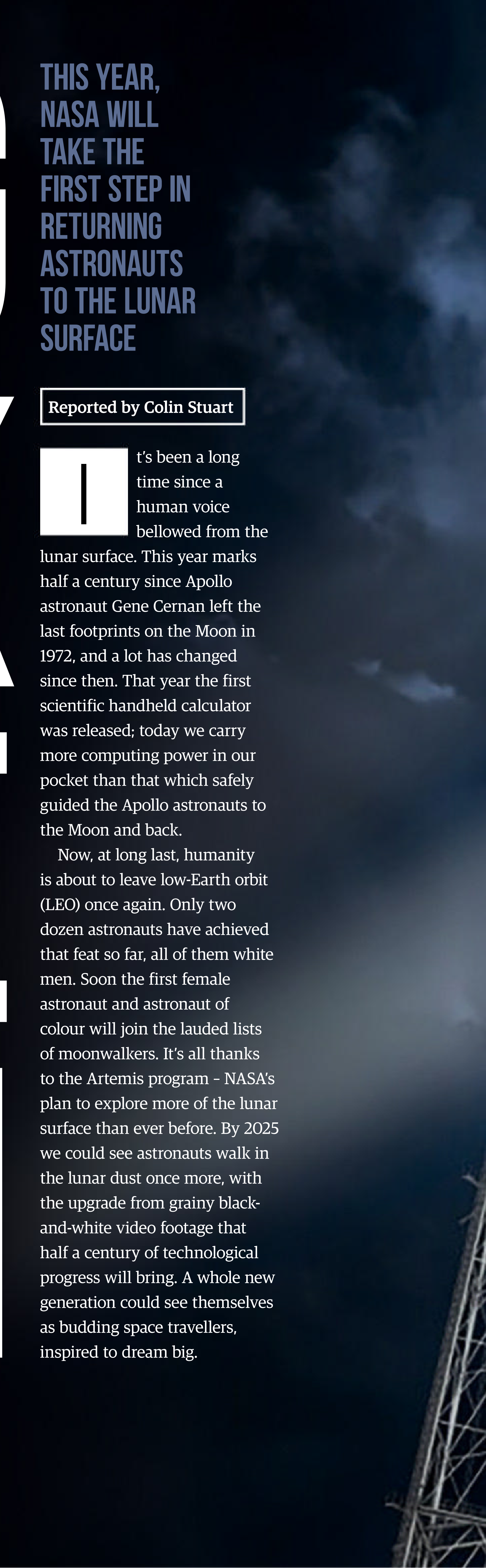
GOING BACK TO THE MOON

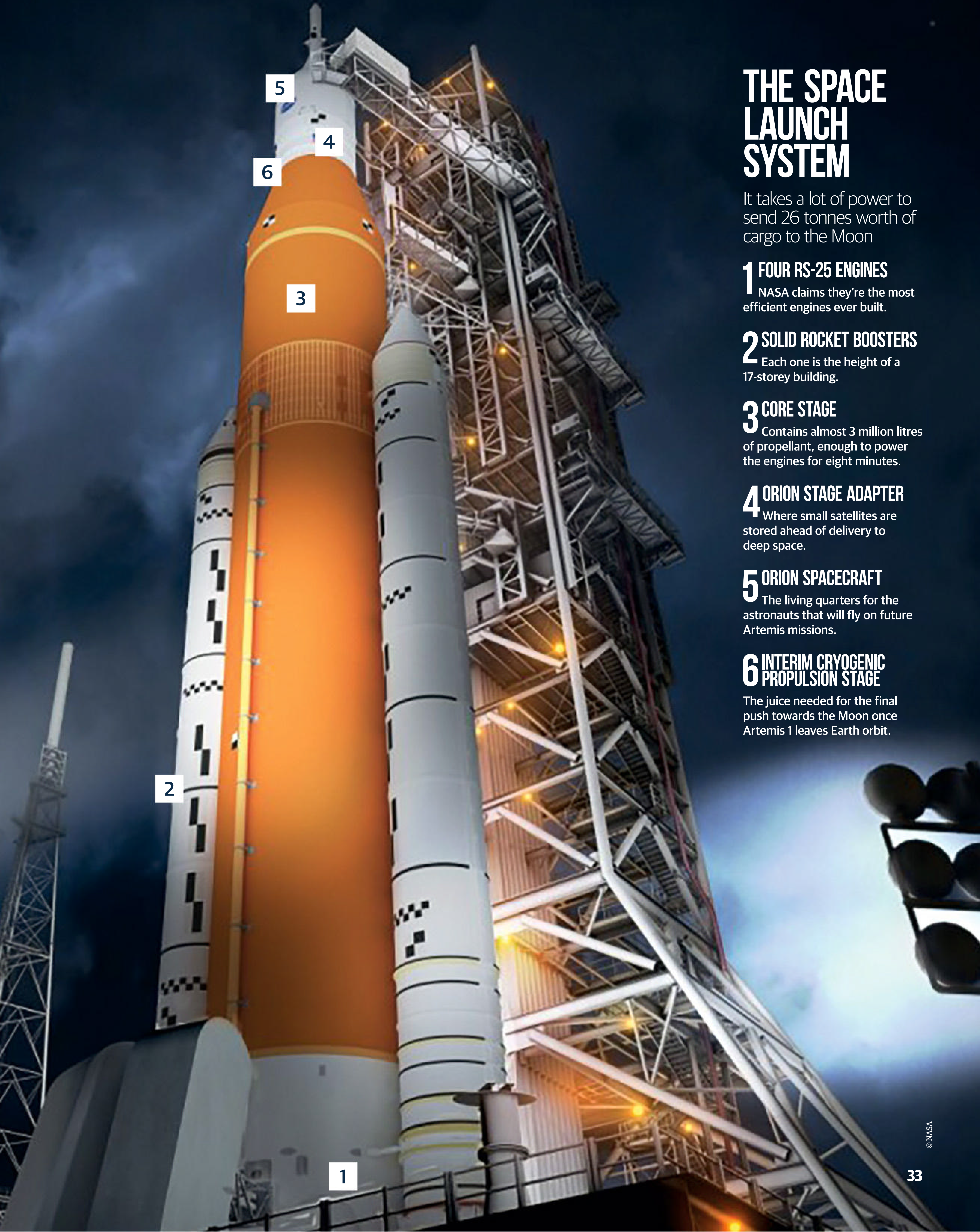
THIS YEAR, NASA WILL TAKE THE FIRST STEP IN RETURNING ASTRONAUTS TO THE LUNAR SURFACE

Reported by Colin Stuart

It's been a long time since a human voice bellowed from the lunar surface. This year marks half a century since Apollo astronaut Gene Cernan left the last footprints on the Moon in 1972, and a lot has changed since then. That year the first scientific handheld calculator was released; today we carry more computing power in our pocket than that which safely guided the Apollo astronauts to the Moon and back.

Now, at long last, humanity is about to leave low-Earth orbit (LEO) once again. Only two dozen astronauts have achieved that feat so far, all of them white men. Soon the first female astronaut and astronaut of colour will join the lauded lists of moonwalkers. It's all thanks to the Artemis program – NASA's plan to explore more of the lunar surface than ever before. By 2025 we could see astronauts walk in the lunar dust once more, with the upgrade from grainy black-and-white video footage that half a century of technological progress will bring. A whole new generation could see themselves as budding space travellers, inspired to dream big.





THE SPACE LAUNCH SYSTEM

It takes a lot of power to send 26 tonnes worth of cargo to the Moon

1 FOUR RS-25 ENGINES

NASA claims they're the most efficient engines ever built.

2 SOLID ROCKET BOOSTERS

Each one is the height of a 17-storey building.

3 CORE STAGE

Contains almost 3 million litres of propellant, enough to power the engines for eight minutes.

4 ORION STAGE ADAPTER

Where small satellites are stored ahead of delivery to deep space.

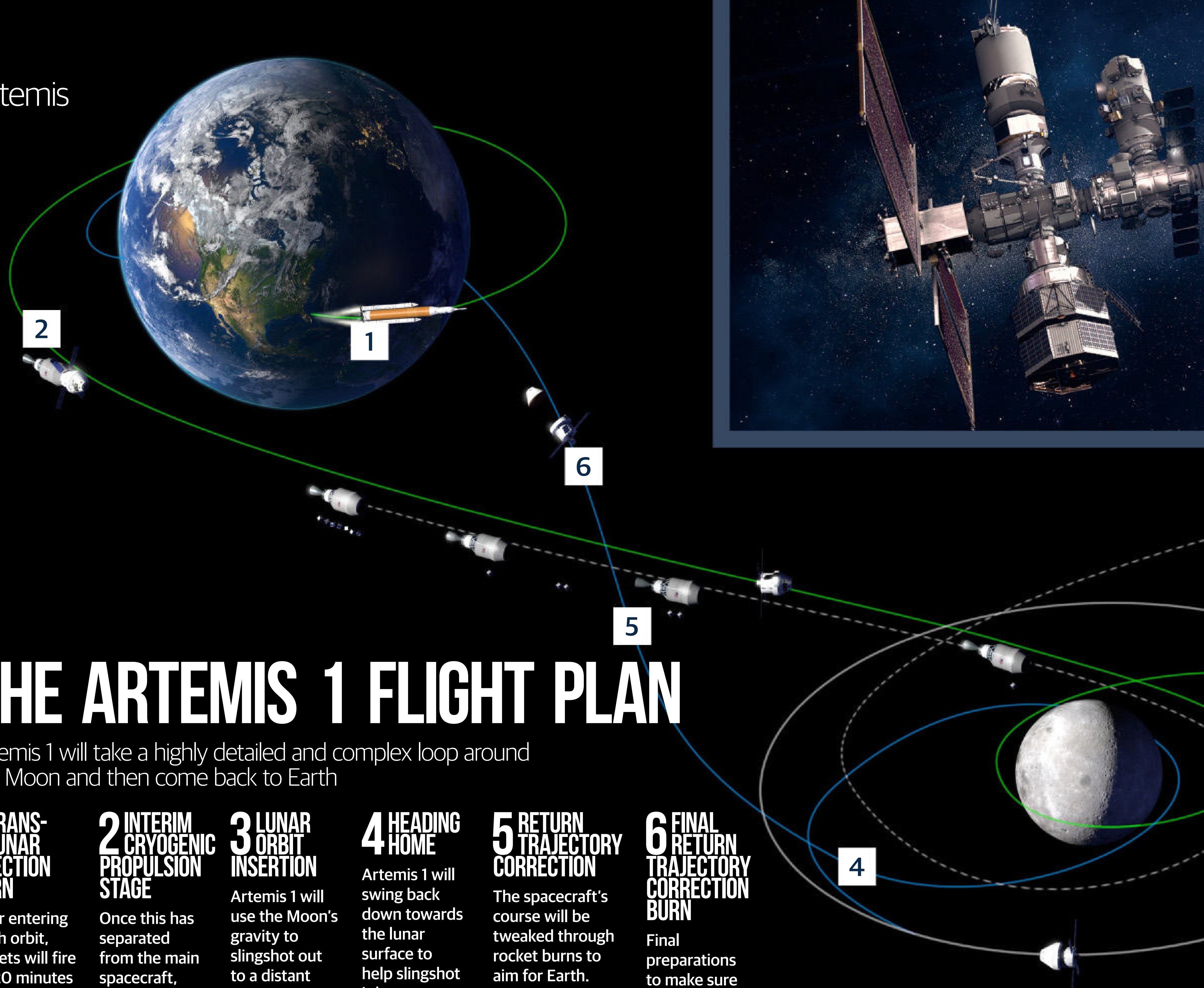
5 ORION SPACECRAFT

The living quarters for the astronauts that will fly on future Artemis missions.

6 INTERIM CRYOGENIC PROPULSION STAGE

The juice needed for the final push towards the Moon once Artemis 1 leaves Earth orbit.

© NASA



THE ARTEMIS 1 FLIGHT PLAN

Artemis 1 will take a highly detailed and complex loop around the Moon and then come back to Earth

1 TRANS-LUNAR INJECTION BURN

After entering Earth orbit, rockets will fire for 20 minutes to send the spacecraft towards the Moon.

2 INTERIM CRYOGENIC PROPULSION STAGE

Once this has separated from the main spacecraft, there's no turning back.

3 LUNAR ORBIT INSERTION

Artemis 1 will use the Moon's gravity to slingshot out to a distant lunar orbit.

4 HEADING HOME

Artemis 1 will swing back down towards the lunar surface to help slingshot it home.

5 RETURN TRAJECTORY CORRECTION

The spacecraft's course will be tweaked through rocket burns to aim for Earth.

6 FINAL RETURN TRAJECTORY CORRECTION BURN

Final preparations to make sure the spacecraft hits the atmosphere at the right angle.

© Adrian Mann

© NASA

Left: A motor that's part of the Launch Abort System on Orion undergoes hot-fire testing in 2019

But pulling this off requires an entirely new launch system – and a bit of practice. This March will see the launch of Artemis 1, an uncrewed test flight. It will be the maiden use of NASA's Space Launch System (SLS), a powerful rocket that will send the new Orion Multi-Purpose Crew Vehicle (MPCV) on a 380,000-kilometre (236,120-mile) journey to the Moon. If all goes to plan then it will be followed by a crewed mission, Artemis 2, in 2024. It will test everything out in Earth orbit, then it's full steam ahead for the history-making Artemis 3 crew to land on the lunar south pole and spend a week there in 2025.

Even without a crew, Artemis 1 will be a record breaker. "Orion will stay in space longer than any ship for astronauts has done without docking to a space station and return home faster and hotter than ever before," says NASA. But first it has to leave Earth. Two huge boosters and a core stage filled with near 3 million litres of propellant will power the rocket through Earth's atmosphere. Once in space, the boosters will be jettisoned and the core stage will separate from the Orion spacecraft atop it. Orion will then orbit the planet while it deploys its solar panels. Finally, the Interim Cryogenic Propulsion Stage (ICPS) will fire to eject Orion from orbit and send it on its way towards the Moon.

Once the ICPS has been discarded it has another job: to deploy a series of tiny satellites that have hitchhiked along for the ride. They include BioSentinel, a mission that will carry yeast samples beyond LEO. The idea is to study radiation levels and their effect on living organisms, providing key insights into keeping astronauts safe when they fly on Artemis 3. After separation from the ICPS, Orion will be propelled and powered by the European Service Module, built by the

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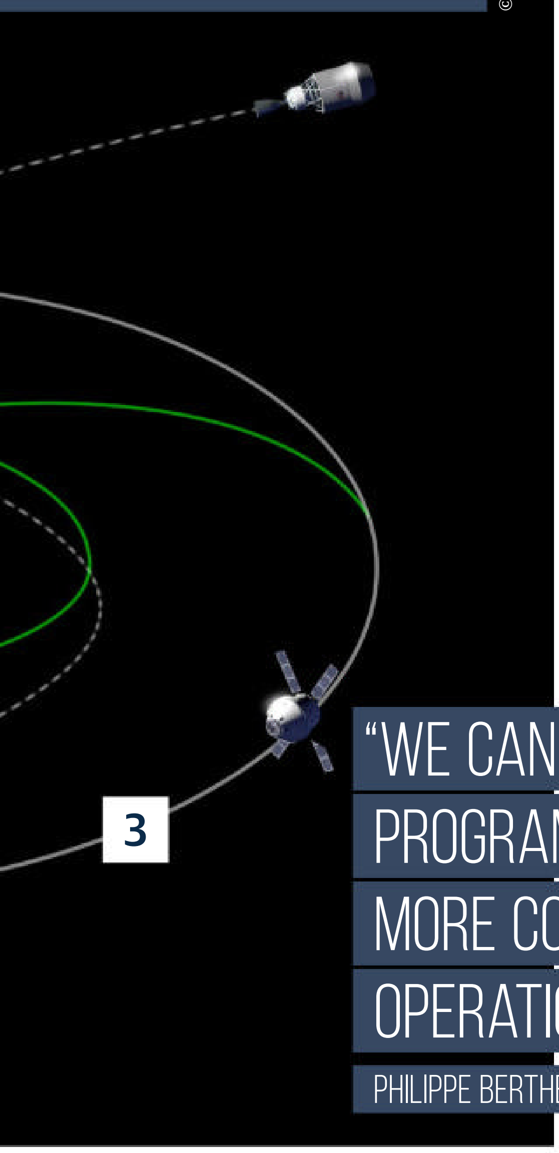


Left: Once completed, Gateway will be like an International Space Station in orbit around the Moon

Right: The Artemis 1 Flight Control Team simulating mission scenarios at Johnson Space Center in Houston

European Space Agency (ESA). “The Service Module will also provide consumables for future crew, including water and oxygen,” says Philippe Berthe, the ESA’s project coordination manager for the module.

Artemis 1 may not have a human crew on board, but the commander’s seat will be occupied by a mannequin dressed in the Orion Crew Survival System - a special suit designed to help protect against radiation. Two radiation sensors will monitor radiation levels. The mannequin will be strapped in, but the weightless environment also needs testing, so NASA is flying a zero-gravity indicator in the form of a Snoopy cuddly toy dressed in an iconic orange NASA jumpsuit. The comic strip character has a long association with lunar exploration - the crew of Apollo 10 used it as a nickname for their Lunar Module.

So how does the new Service Module compare to the Lunar Modules that sent Apollo astronauts to the Moon? “The propulsion is largely the same; it’s very comparable to the Apollo era,” says Berthe. Yet half a century of technological progress has brought other strides forward. “There have been vast improvements in solar cells,” Berthe explains, so that’s where the spacecraft will derive most of its power. “Computing power is another major improvement,” says Berthe. The Apollo astronauts famously flew to the Moon with less computing power than can be found in an iPhone. That meant a lot of manual tasks for the crew. This time around, the spacecraft’s powerful computers can do most of the heavy lifting. “We can program much more complex operations now. The crew don’t need to intervene directly in every nitty-gritty detail,” Berthe says.

Artemis 1 will be gone for between 26 and 42 days. It’ll take one or two weeks to get to the Moon, where it will swoop down close to the lunar surface and use the gravitational kick it receives to enter a so-called ‘distant retrograde orbit’. Retrograde means that it will orbit the Moon in the opposite direction to that in which the Moon spins. It will stay in that orbit for between 6 and 19 days, and then it will swing back down towards the Moon for another kick to help power its 9 to 19 day journey back to Earth.

This project has been a labour of love for Berthe, who has been involved with it for nearly two decades and has seen many obstacles come and go. “One of the biggest challenges has been maintaining support across four administrations,” he says. Presidents Bush, Obama, Trump and Biden have all wanted to put their spin on it and whether they wanted to go to the Moon or Mars. The timeline has also moved around, from a landing in 2028, then 2024 and now 2025. “The mission has changed a lot of times,” Berthe says.

On top of the politics came the coronavirus pandemic, although Berthe says it didn’t have as big an impact as he feared. “It was difficult for

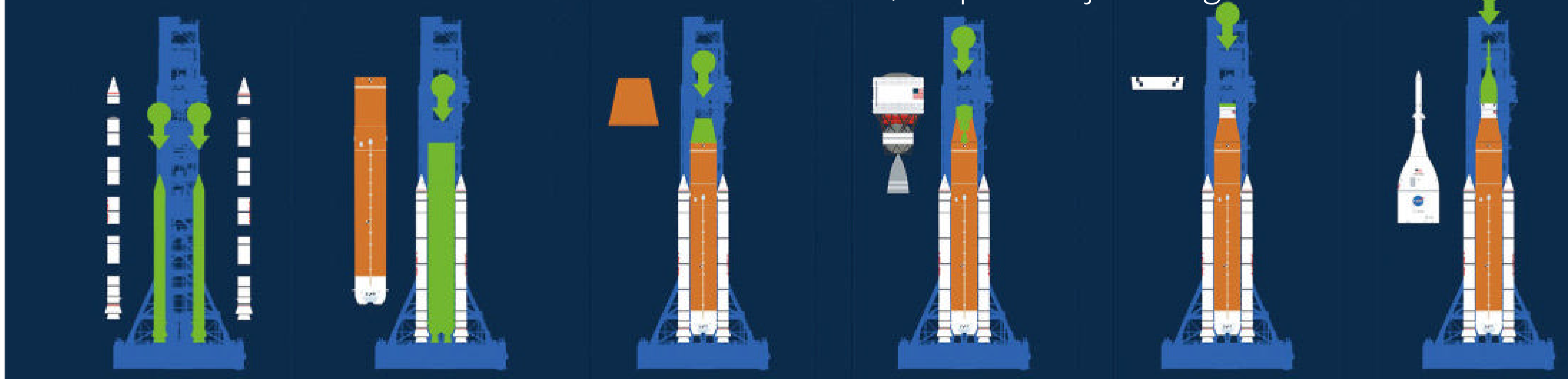
> “WE CAN PROGRAM MUCH MORE COMPLEX OPERATIONS NOW”
>
> PHILIPPE BERTHE

MISSION CONTROL CENTER
EECOM

© NASA

STACKING THE ROCKET

Before it can launch, the parts are joined together



1 SOLID ROCKET BOOSTERS

The boosters are added first. Each one has five segments stacked on top of each other.

2 CORE STAGE

The rocket’s huge core stage is then placed between the two rocket boosters.

3 LAUNCH VEHICLE STAGE ADAPTER

The LVSA goes on top of the core stage to allow the rest of the bits to be added.

4 INTERIM CRYOGENIC PROPULSION STAGE

This is bolted into the top of the Launch Vehicle Stage Adapter.

5 ORION STAGE ADAPTER

This piece is specific to the spacecraft being used and is used to mate it to the rocket.

6 ORION SPACECRAFT

The preassembled Orion spacecraft, which carries the crew, is the last piece of the puzzle.

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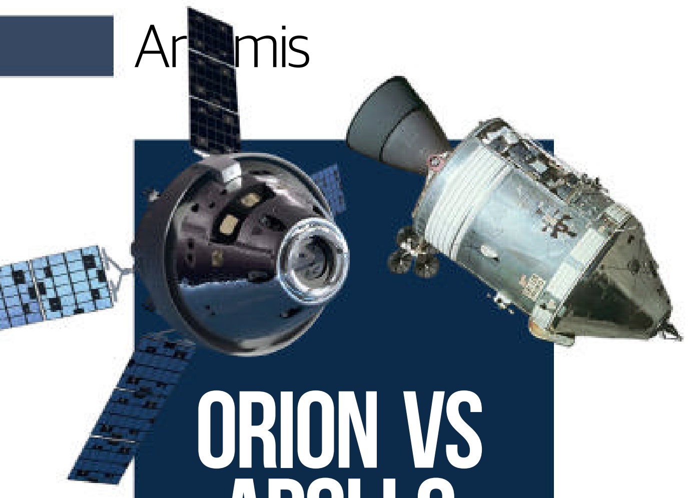

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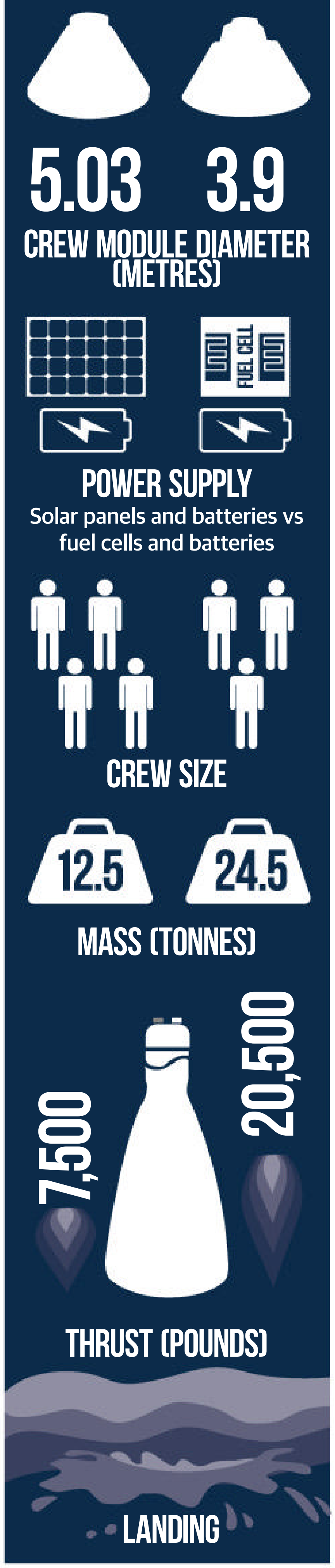
ORION VS APOLLO

How does the new Orion spacecraft compare to its Apollo predecessors?



people to cross international borders," he says. For a huge multi-agency project like this, that "somewhat slowed us down". There are also plenty of naysayers – those who argue that sending humans back to the Moon is a waste of time, money and resources. We've already done it, so why go back? Especially as we've already sent an armada of robotic spacecraft to both scan the Moon from orbit and drive across its surface. "An astronaut will do in six hours what a robot can do in six months," Berthe says. "It's more expensive, but it's more efficient."

We ultimately also want more than just fleeting visits. "We want to stay permanently and build something sustainable for the long run," Berthe says. To this end, an orbital outpost called Gateway is a big part of the Artemis program. Think of it like an International Space Station, but in orbit around the Moon – a home considerably further away from home. It could be ready as soon as November 2024 and it is intended to last for 15 years. The hope is that it will be ready in time for the crew of Artemis 3 to dock with.

While aboard Gateway, astronauts will stay in the Habitation and Logistics Outpost (HALO). There are also additional docking ports for cargo ships to come and go with supplies. Astronauts would then transfer to the Starship Human Landing System (HLS), a lunar lander based on SpaceX's existing Starship. However, if Gateway isn't ready then the crew will transfer directly to the HLS for landing at Artemis Base Camp.

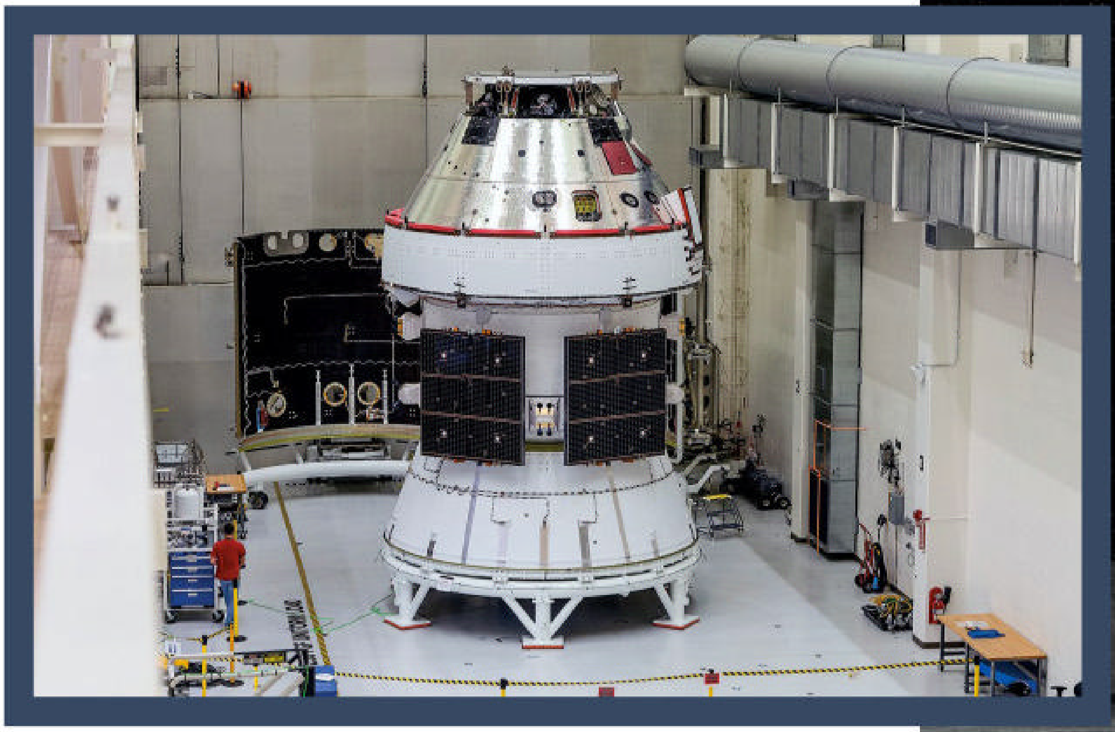
Initially, stays will be short and largely inside the lander, but ultimately NASA wants astronauts living on the lunar surface for at least a month at a time in purpose-built accommodation. In September 2021 the agency put out a call for companies to submit their proposals for the next generation of spacesuits that Artemis astronauts will wear during their history-making moonwalks.

Eventually, the space between Earth and the Moon could be swarming with spacecraft ferrying goods and astronauts back and forth. Jeff Bezos, the founder of Amazon and CEO of space travel company Blue Origin, has suggested that the Moon could be a place to put our heavy industry, the idea being that it would free up living space on Earth and move our atmosphere-polluting infrastructure somewhere where there isn't even an atmosphere.

The Moon is also an ideal staging post for deeper Solar System exploration. The size and scale of the SLS shows just how hard we have to work to escape from Earth's gravitational clutches. The Moon's gravity, which is six times weaker than ours, is considerably easier to flee from. As past missions have discovered, there's also a huge amount of water on the Moon. As water is H_2O, that means an abundant supply of oxygen. In fact, the Moon's top layer alone has enough oxygen to sustain 8 billion people for 100,000 years.

Liquid oxygen is also rocket propellant. That's why Artemis Base Camp will be at the Moon's south pole. We already know that there's plenty

Below: The Orion spacecraft being prepared at Kennedy Space Center in Florida



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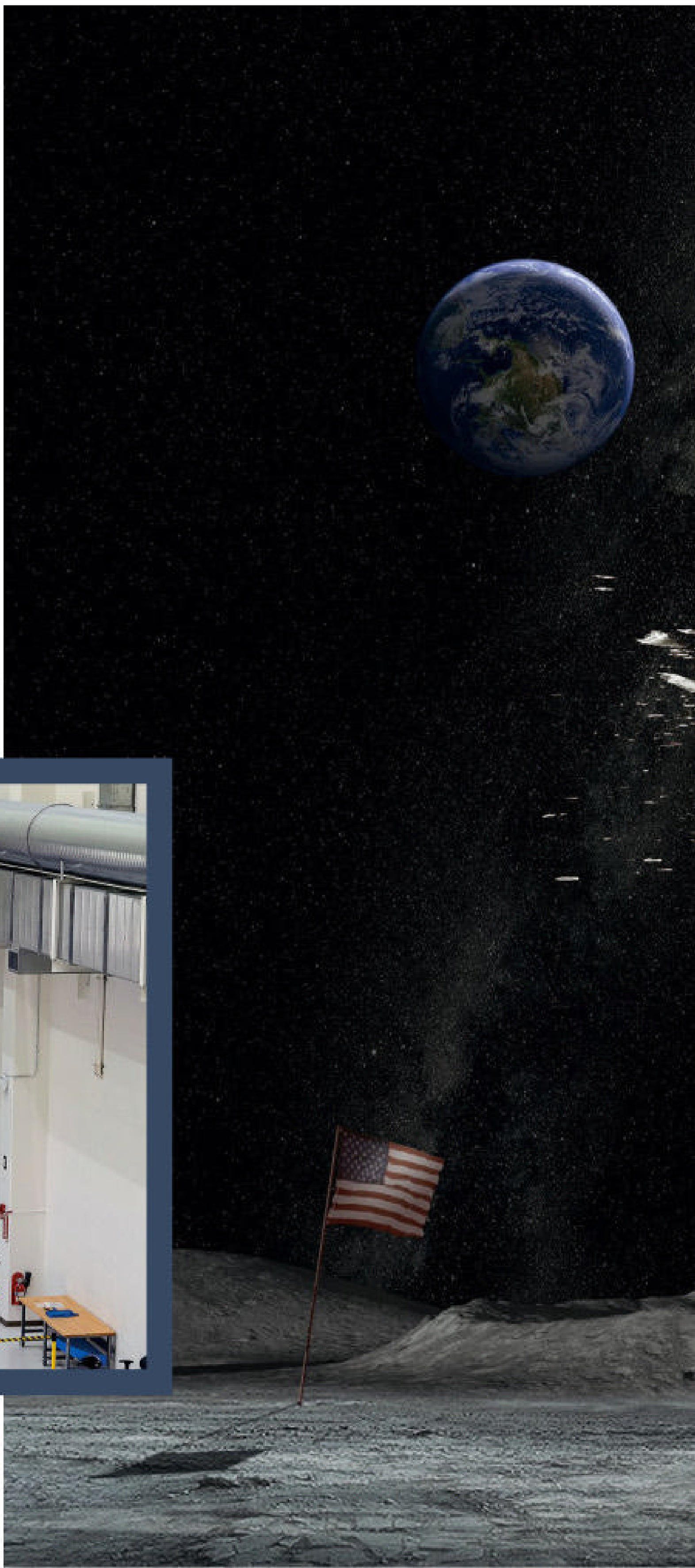
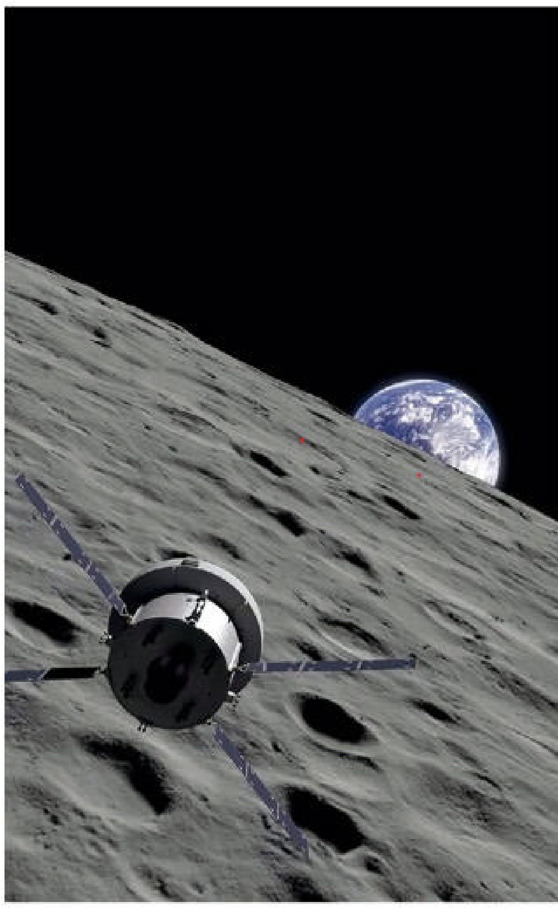


of water there. Lunar Flashlight, one of the small spacecraft hitching a ride on Artemis 1, will orbit the Moon and shine infrared lasers into permanently shadowed craters near the lunar poles to further reveal the quantity and quality of water ice there. The sunlight at the south pole is also favourable – it's illuminated approximately 90 per cent of the time, compared to two weeks of daylight followed by two weeks of darkness on the rest of the Moon. That's good news for a colony powered by solar panels. The combination of these two factors may lead to a time when rocket ships routinely fuel up close to Artemis Base Camp and blast off for more distant destinations, such as Mars and the asteroid belt.

Former NASA administrator Jim Bridenstine certainly sees lunar exploration as a key step on our journey towards becoming an interplanetary species. He has said that "we need several years in orbit and on the surface of the Moon to build operational confidence for conducting long-term work and supporting life away from Earth before we can embark on the first multi-year human mission to Mars".

It's all part of returning to where we came from. The iron in your blood and the calcium in your bones was forged inside stars that blasted them across the universe when they died. Eventually those atoms found themselves inside sentient creatures who dreamed of sailing between the stars and built cathedral-sized rocket ships to take them there. The Artemis 1 launch later this year may only be a small step, but it's an important one. Future historians could look back on it as the moment humanity took a giant leap in its return to the Moon, this time for good.

Colin Stuart
Science author and speaker
Colin holds a degree in astrophysics, has written over 17 books on space and has an asteroid named in his honour: 15347 Colinstuart.



Right: An Orion spacecraft witnessing Earthrise over the craggy lunar surface

Below: Artist's impression of an ascent vehicle beginning the journey back to Earth

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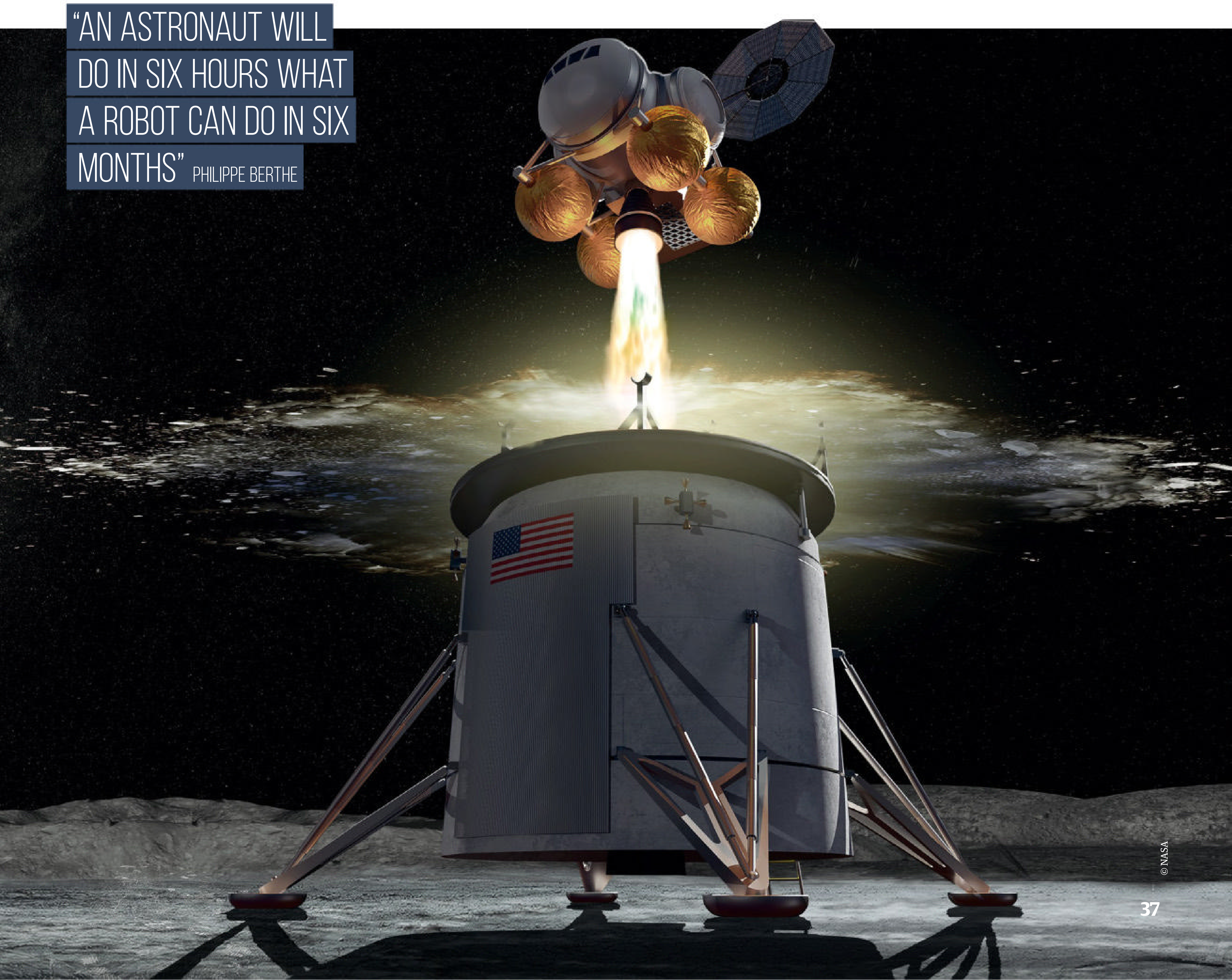
"AN ASTRONAUT WILL DO IN SIX HOURS WHAT A ROBOT CAN DO IN SIX MONTHS" PHILIPPE BERTHE



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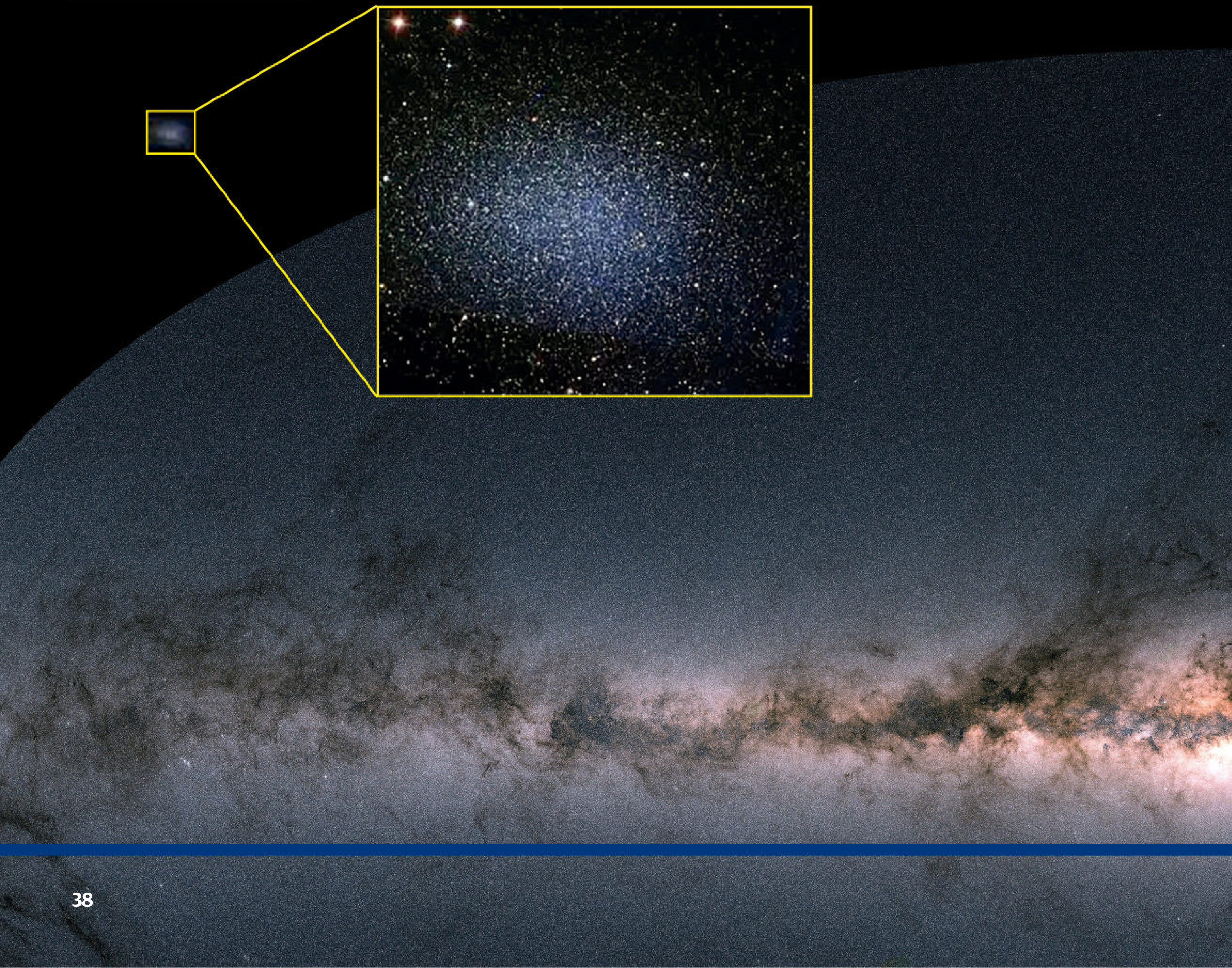
BLACK HOLE IN MILKY WAY'S SATELLITE DEFIES EXPLANATION

Dwarf galaxy Leo I's giant central area seems too big for such a small host

Reported by Tereza Pultarova



A tiny galaxy orbiting at the outskirts of the Milky Way appears to have a giant black hole at its centre, comparable to that of the much larger Milky Way itself, and scientists don't know why. The Leo I dwarf galaxy, some 820,000 light years from Earth, is only about 2,000 light years across. Until now, astronomers thought the galaxy's mass was about 15 to 30 million times the mass of our Sun. That's tiny compared to the Milky Way, which is estimated to weigh as much as 1.5 trillion Suns and whose disc is over 100,000 light years wide. Unexpectedly, at the heart of little Leo I sits a black hole that's nearly as large as the one at the heart of the Milky Way. The discovery defies expectations, as astronomers believed giant black holes grew from collisions between galaxies and should correspond with the galaxy's size.

"There is no explanation for this kind of black hole in dwarf spheroidal galaxies," María José Bustamante, an astronomy doctoral graduate at the University of Texas at Austin, said.

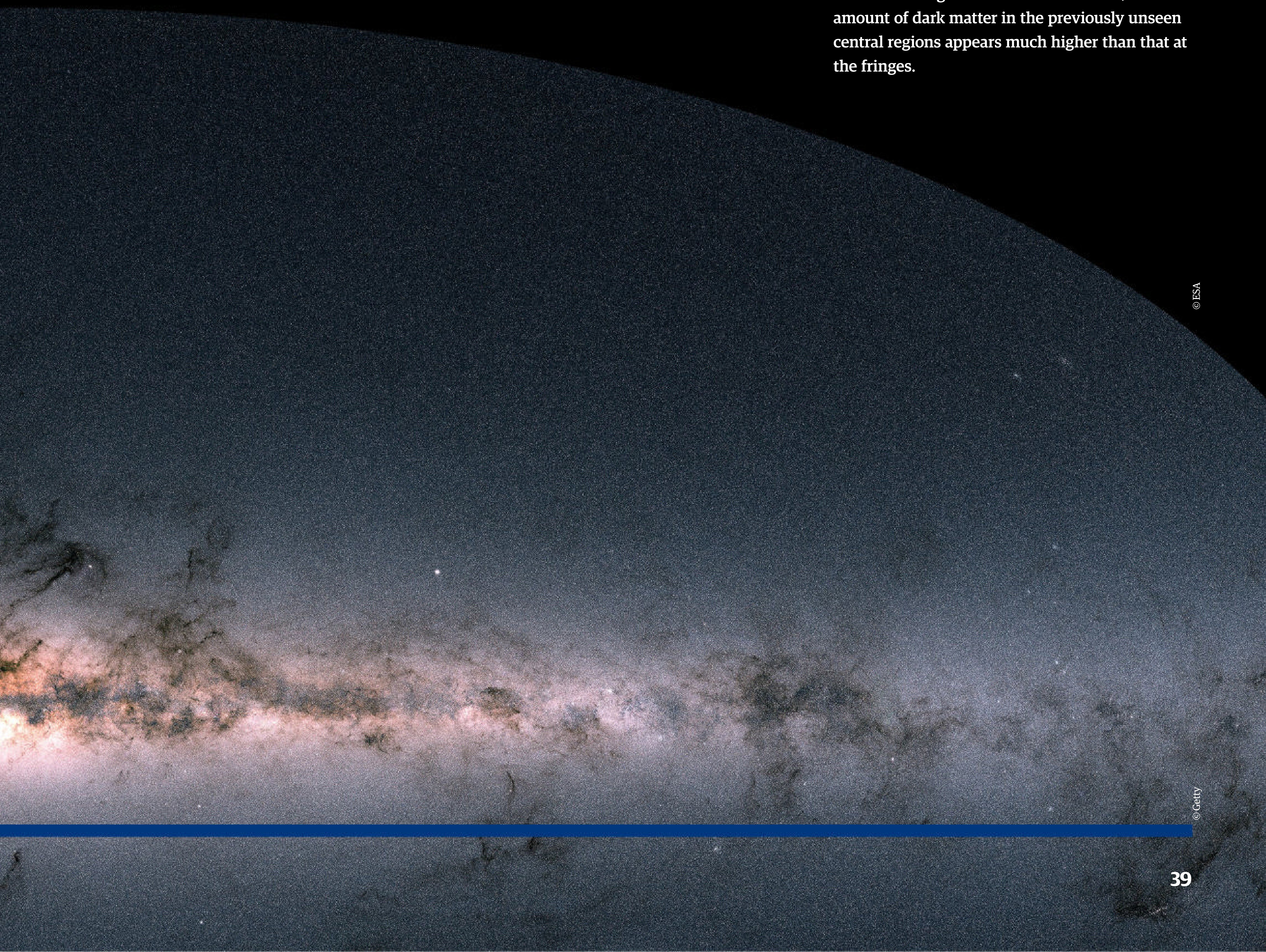
> "THERE IS NO EXPLANATION FOR THIS KIND OF BLACK HOLE IN DWARF SPHEROIDAL GALAXIES"
>
> MARÍA JOSÉ BUSTAMANTE

The discovery came by chance. Scientists set out to measure the amount of dark matter in Leo I using the Virus-W instrument on the McDonald Observatory's Harlan J. Smith Telescope, which measures the motion of stars in small galaxies around the Milky Way and infers the amount of dark matter in those galaxies from that motion. Dark matter is invisible, but scientists can measure its concentrations in the universe based on its effects on orbits and velocities of nearby stars. The more dark matter in the star's orbit, the faster it travels.

When the team ran data gathered in the observations through their computer models, they found that Leo I appears to have basically no dark matter, but a black hole at its centre as heavy as 3 million Suns. The Sagittarius A* black hole at the centre of the Milky Way is only 25 per cent larger. "You have a very small galaxy that is falling into the Milky Way, and its black hole is about as massive as the Milky Way's," Karl Gebhardt, an astrophysicist also at UT Austin, said. "The mass ratio is absolutely huge."

The results differ from previous calculations of dark matter in Leo I, the astronomers admitted. The astronomers said previous studies were based on less precise data and didn't have access to such powerful supercomputers as the Austin team.

In previous studies, scientists didn't see the denser inner regions of the galaxy and mostly focused on accessible information about a few individual stars. These datasets, however, seemed to contain a disproportionate number of slow stars. Calculations based on these biased datasets then failed to reveal the dark matter in the inner regions. In the case of Leo I, the amount of dark matter in the previously unseen central regions appears much higher than that at the fringes.



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STAR PROFILE

RIGEL

Orion's brightest star is a powerful blue supergiant

Rigel – also known as Beta Orionis – is a rare blue supergiant and the brightest star in the constellation of Orion (the Hunter). Rigel is nearing the end of its life; having exhausted most of the hydrogen fuel in its core, the blazing-blue, hot star will one day end in a spectacular supernova, though this won't be for another few million years. The dazzling beauty is part of a multi-star system with several companion stars.

Rigel is a variable star that lies about 870 light years away from the Sun and is about 120,000 times as luminous. Rigel's name is popular in science fiction. It's in the name of a number of planets in the *Star Trek* universe, is mentioned in *The Hitchhiker's Guide to the Galaxy* and is also featured in a number of other novels, computer games and comic books. The name comes from an Arabic phrase, 'Rijl Jauzah al Yusra', which means 'the left leg of the Jauzah'. The phrase is sometimes translated as 'the left leg of the giant', referring to the constellation of Orion, which Rigel is a part of.

Rigel is easy to spot in the winter sky, shining at a magnitude of +0.12, making it the seventh-brightest star in the sky. Though as Rigel's brightness varies, it occasionally climbs the charts and outshines Auriga's brightest star Capella, briefly becoming the sixth-brightest star in the sky. To locate Rigel you need to first identify the constellation of Orion. Orion is located on the celestial equator and can be seen throughout the entire world. Finding Orion's Belt is the easiest way to locate the constellation. Orion's Belt is formed by three bright stars: Alnilam, Mintaka and Alnitak. Orion is in the southwestern sky if you are in the Northern Hemisphere or the northwestern sky if you are in the Southern Hemisphere. It is best seen between latitudes of 85 and -75 degrees. Once you have located Orion in the sky, Rigel can be found in the lower corner of the constellation and is easy to distinguish from nearby stars due to its blue-white colour.

Rigel is actually the largest star in a multi-star system. It has three companion stars, though two are so close together they are often treated as the same star. Companion stars Rigel B and Rigel C are so close together – separated by less than 0.3 arcseconds – that they are only visible to telescopes that have a high resolving power. The pair have apparent magnitudes of +7.5 and +7.6 and orbit each other every 63 years. Even harder to distinguish are the two stars that form Rigel B. Both Rigel Ba and Rigel Bb are so close to one another they can only be detected through spectroscopic observations.

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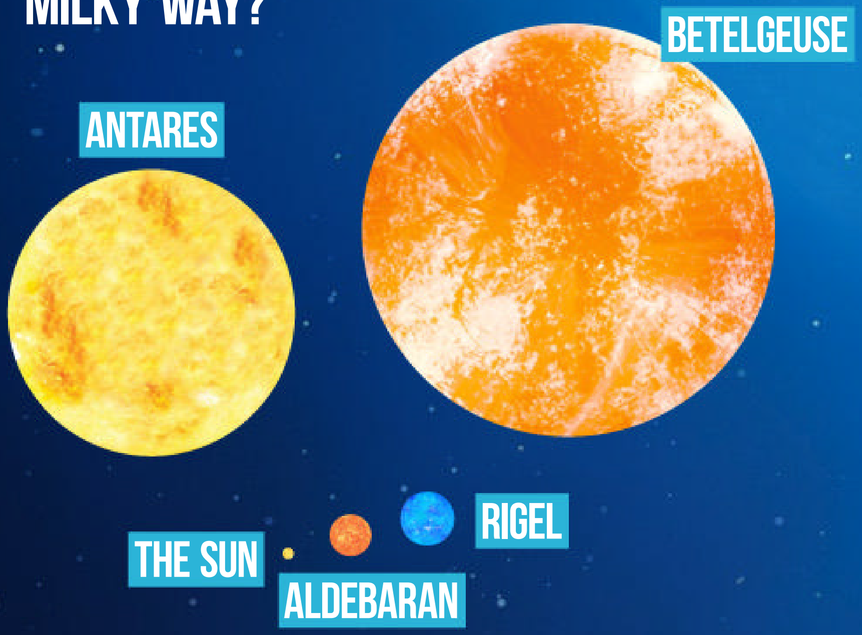
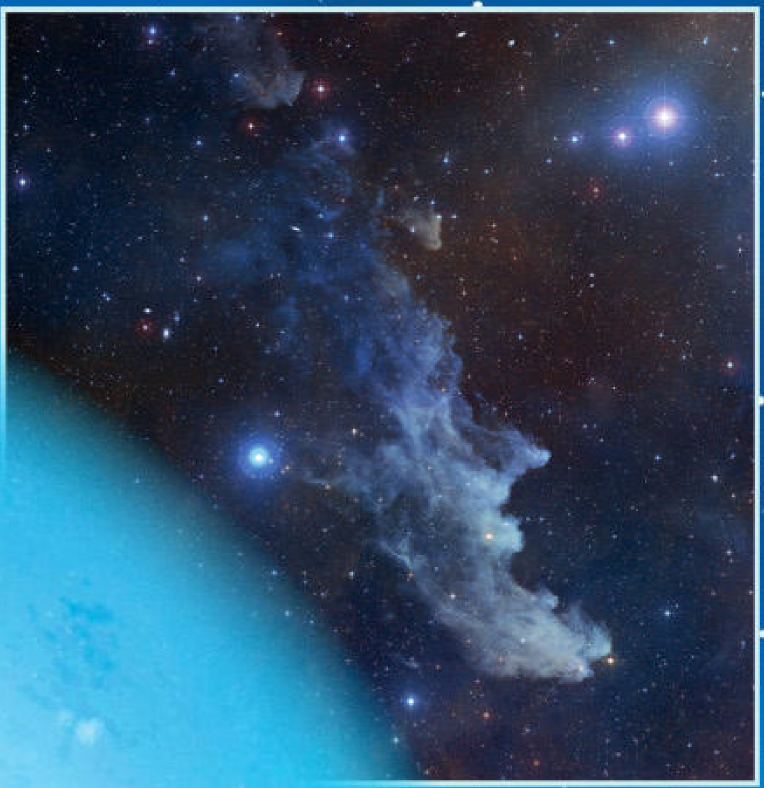
HOW DOES RIGEL COMPARE TO OTHER STARS IN THE MILKY WAY?





© NASA

Above: Light from Rigel reflects off the dust composing the Witch Head Nebula, illuminating it

RIGEL'S LOCATION

RIGHT ASCENSION:
05H 14M 32.3S

DECLINATION:
-8° 12' 0.6"

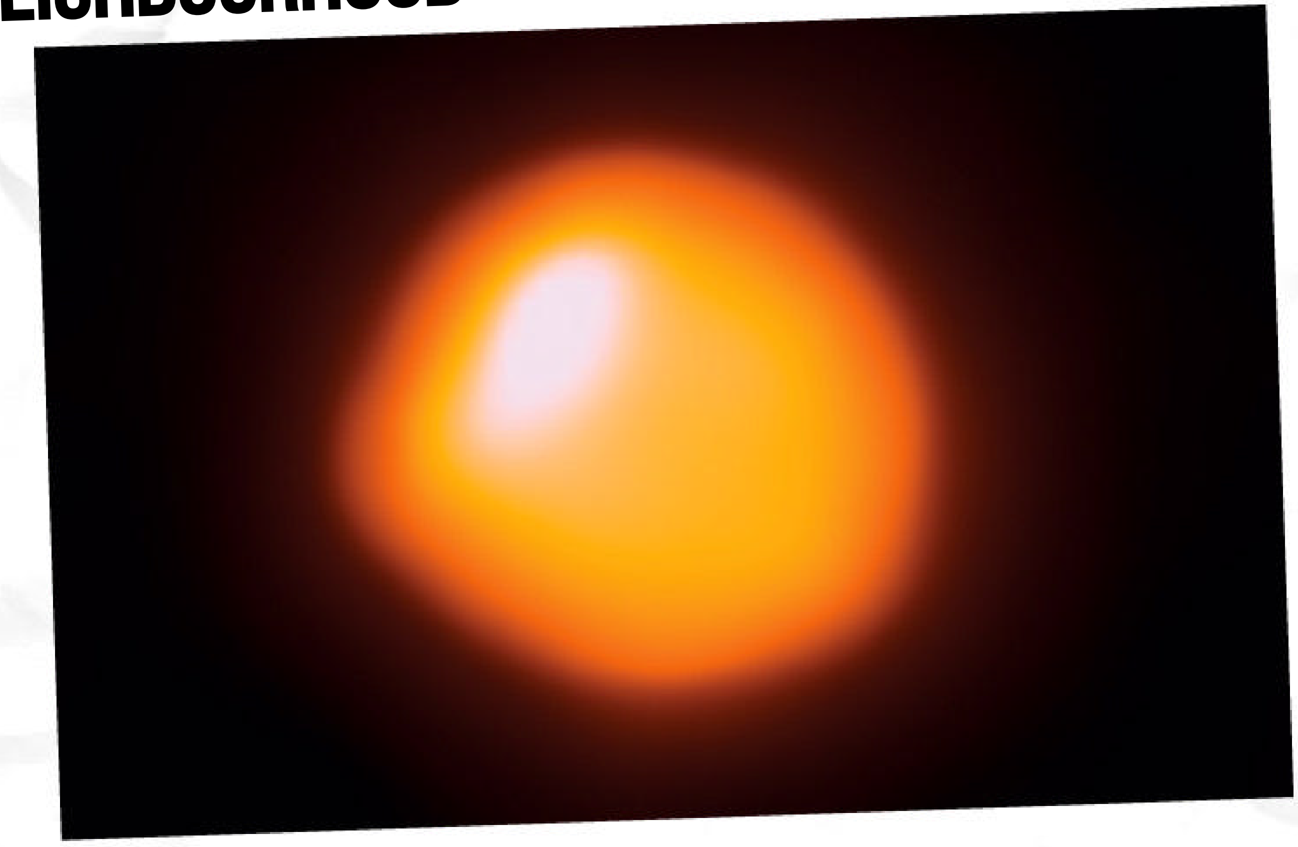
> "RIGEL IS ACTUALLY THE LARGEST STAR IN A MULTI-STAR SYSTEM – IT HAS THREE COMPANION STARS"

NEWS FROM RIGEL'S NEIGHBOURHOOD

MYSTERIOUS DIMMING OF BETELGEUSE

The strange dimming seen in 2020 of the huge star Betelgeuse may be from giant sunspots and temperature fluctuations. A new study suggests a 'large dark spot' led to Betelgeuse's surface temperature dropping, which in turn contributed to a temporary dimming in the red giant's luminosity or inherent brightness. The study looked at molecules in the spectra – or light signature – of Betelgeuse to try to figure out what was going on.

When Betelgeuse was at its dimmest on 31 January 2020, its effective temperature, meaning the temperature calculated from its emitted radiation, was measured at 3,476 degrees Kelvin. But once the star was back to a normal luminosity, measurements indicated an almost five per cent temperature rise to 3,646 Kelvin. Given that Betelgeuse could still be many hundreds of years from going supernova, astronomers concluded it is unlikely the entire surface cooled temporarily by that amount. They posited that it must have been a sunspot blocking some of Betelgeuse's radiation from escaping.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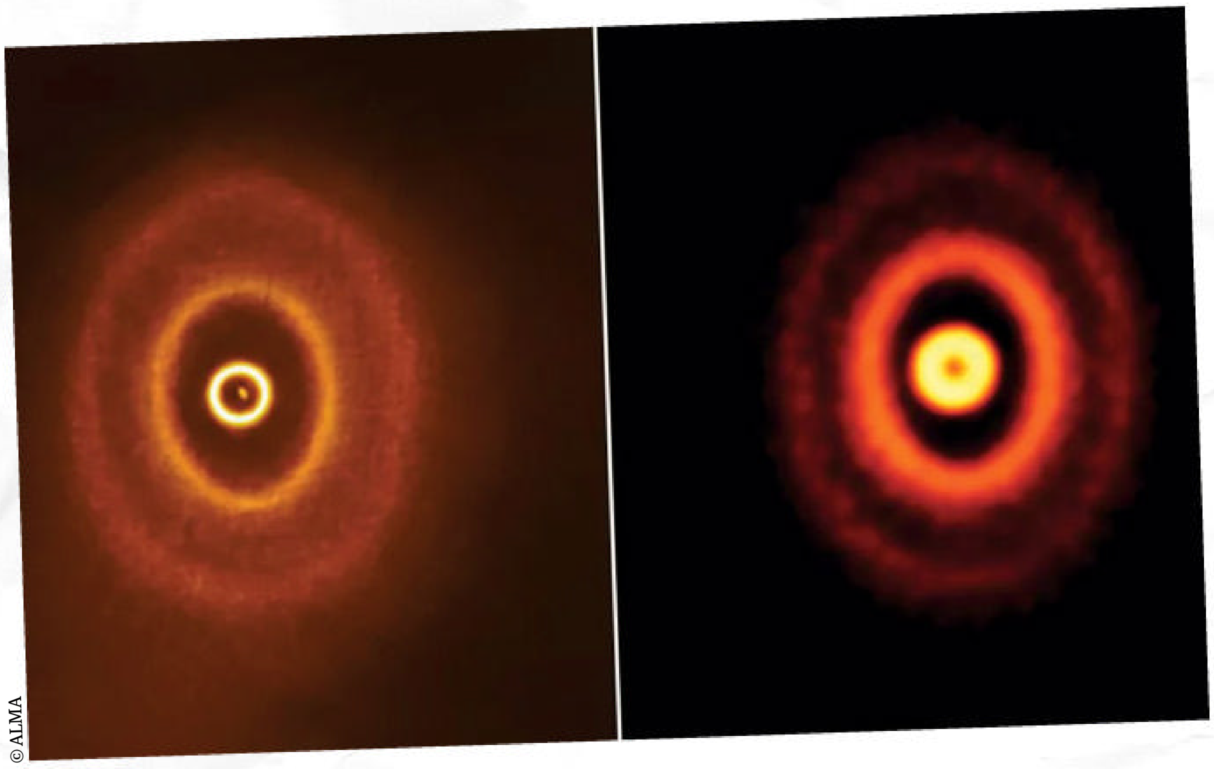
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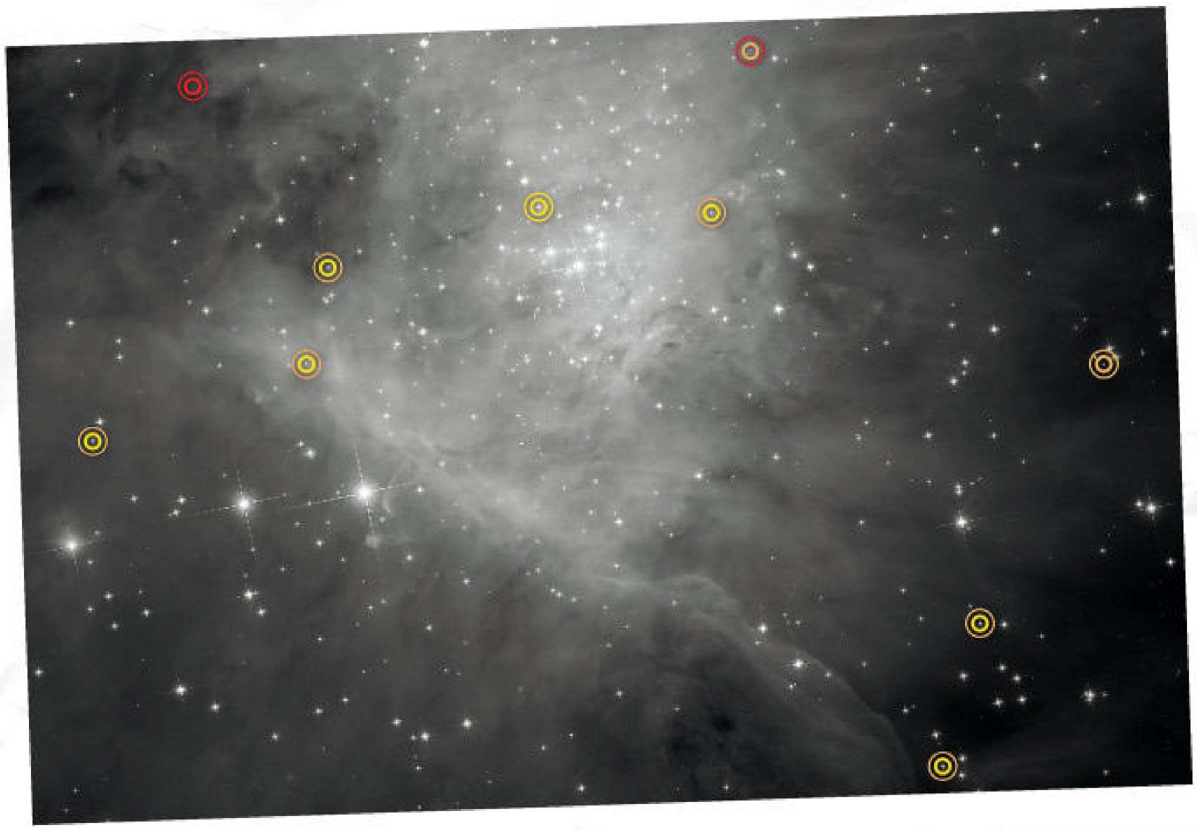
A THREE-SUN PLANET IN ORION'S NOSE

There's now even more evidence that a bizarre star system perched on the constellation of Orion's nose may contain the rarest type of planet in the known universe: a single world orbiting three suns simultaneously. A 2021 study offers fresh evidence for the rare planet's existence. Researchers conducted 3D simulations to model how the mysterious gaps in the star system's rings could have formed, based on observations of other dust rings, or protoplanetary discs, elsewhere in the universe. The team tested two hypotheses: either the break in GW Orionis' rings formed from the torque applied by the three twirling stars at the system's centre, or the break appeared when a planet formed within one of the rings. The researchers concluded that there's not enough turbulence in the rings for the stellar torque theory to work. The models suggest that the presence of an enormous, Jupiter-size planet – or perhaps several planets – is the likelier explanation for the rings' strange shape and behaviour.

BROWN DWARFS IN THE ORION NEBULA

In 2018, Hubble uncovered a large population of brown dwarfs in the Orion Nebula during a deep survey of the region. Brown dwarfs start out like any other star – from a cloud of gas and dust, with gravity pulling in the components tightly, forming a young protostar at the centre. For main sequence stars, the gravity pushes inwards until hydrogen fusion begins in the core. Brown dwarfs, however, fail to reach this crucial stage. Instead they reach a stable state. Brown dwarfs give off very little light and heat and can therefore be tricky to locate – they were merely theoretical objects until the late 1980s.

One way of finding brown dwarf stars is to look for hot water vapour in their atmospheres. But due to the absorbing effects of water vapour in our own atmosphere, this is challenging to do from Earth. However, the Hubble Space Telescope, residing high above the atmosphere, is well positioned to spot water on distant worlds with its near-infrared vision. During this survey, researchers were able to identify 16 candidate brown dwarf companions to red dwarf stars, one brown dwarf pair and one brown dwarf with a planetary companion.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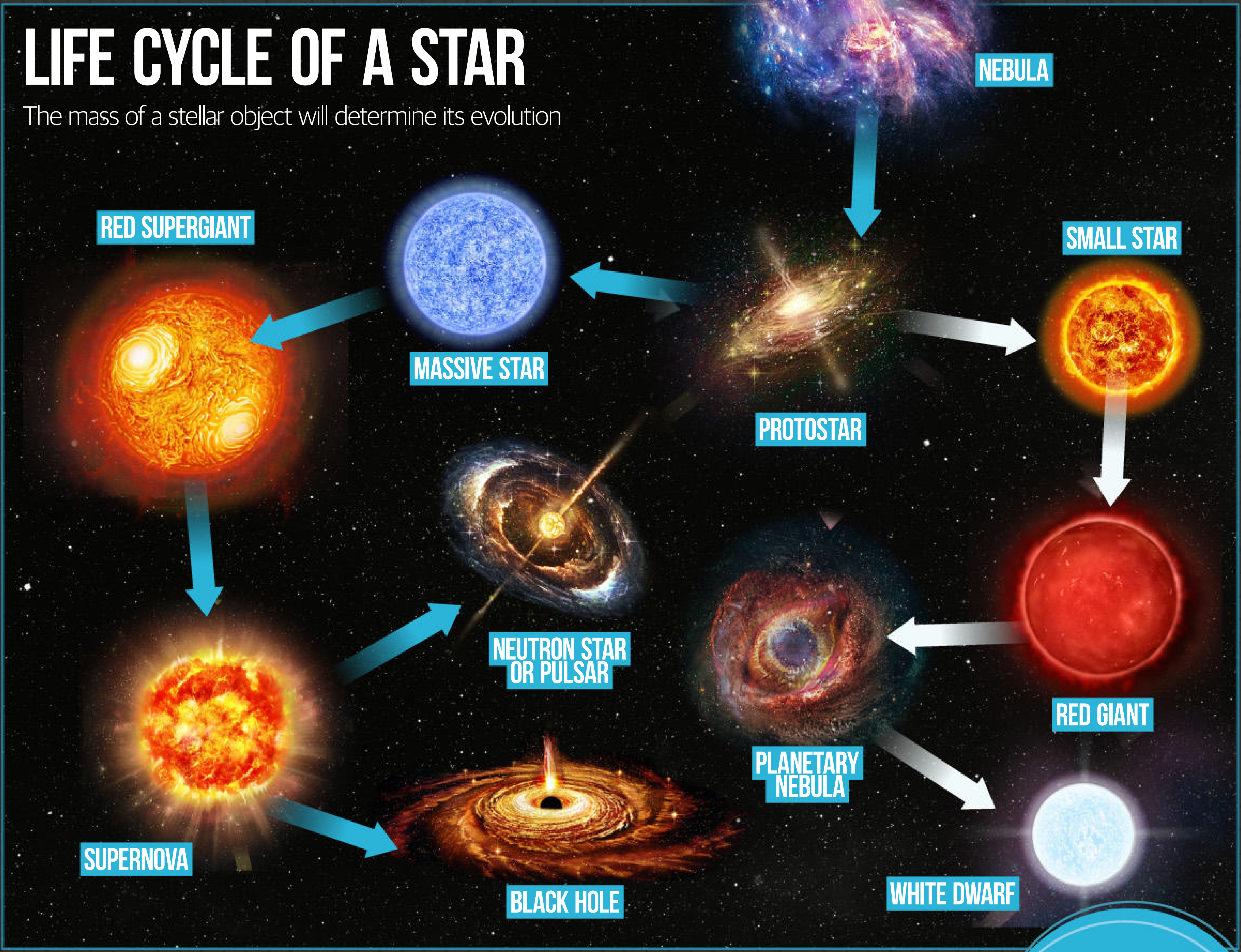
LIFE CYCLE OF A STAR

The mass of a stellar object will determine its evolution


NEBULA
PROTOSTAR
MASSIVE STAR
RED SUPERGIANT
SUPERNOVA
NEUTRON STAR OR PULSAR
BLACK HOLE
SMALL STAR
RED GIANT
PLANETARY NEBULA
WHITE DWARF

RIGEL BY NUMBERS

8 MILLION YEARS
Approximate age of Rigel

79
times the diameter of the Sun

4
Number of stars in the Rigel star system

120,000
times more luminous than the Sun

870 LIGHT YEARS
Approximate distance to Rigel

21
times more massive than the Sun

11,600°C
Approximate surface temperature

> "RIGEL IS EASY TO SPOT IN THE WINTER SKY, SHINING AT A MAGNITUDE OF +0.12"

WHAT IS A LIGHT YEAR?

How we measure vast distances across the universe

Reported by Tim Childers and Jon Gordon

A light year is a measurement of distance and not time, as the name might suggest. A light year is the distance a beam of light travels in a single Earth year, or around 9.7 trillion kilometres (6 trillion miles). On the scale of the universe, measuring distances in kilometres or miles just doesn't cut it. In the same way that you may measure the distance to the supermarket in the time it takes to drive there, astronomers measure the distances of stars in the time it takes for their light to travel to us. For example, the nearest star to our Sun, Proxima Centauri, is 4.2 light years away.

Unlike the speed of your car when travelling on different roads or in traffic, the speed of light is constant throughout the universe and is known to high precision. In a vacuum, light travels at 1,079,252,849 kilometres (670,616,629 miles) per hour. To find the distance of a light year, you multiply this speed by the number of hours in a year - 8,766. Therefore one light year equals 9.5 trillion kilometres (5.88 trillion miles). At first glance this may seem like an extreme distance, but the enormous scale of the universe dwarfs this length.

Measuring distances in kilometres or miles at an astronomical scale would be extremely cumbersome and impractical. Starting in our cosmic neighbourhood, the closest star-forming region to us, the Orion Nebula, is a short 12,651,053,184,000,000 kilometres (7,861,000,000,000,000 miles) away. Or, more simply, 1,300 light years away. The centre of our galaxy is about 27,000 light years away. The nearest spiral galaxy to ours, the Andromeda Galaxy, is 2.5 million light years away. Some of the most distant galaxies we can see are billions of light years from us.

Measuring in light years also allows astronomers to determine how far back in time they are viewing. Because light takes time to

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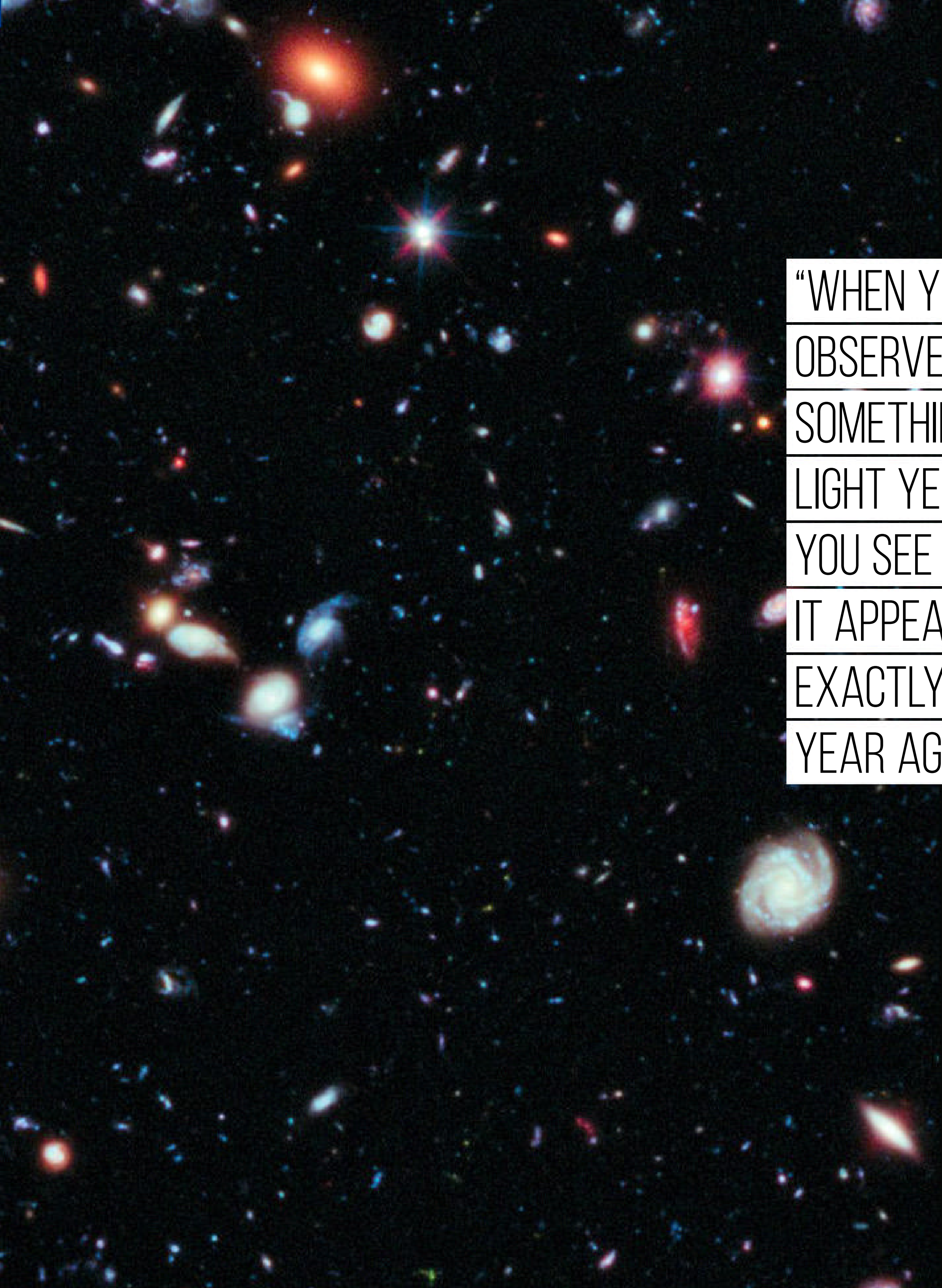


travel to our eyes, everything we view in the night sky has already happened. In other words, when you observe something a light year away, you see it as it appeared exactly one year ago. We see the Andromeda Galaxy as it appeared 2.5 million years ago. The most distant object we can detect, the cosmic microwave background, is also our oldest view of the universe, occurring just after the Big Bang some 13.8 billion years ago.

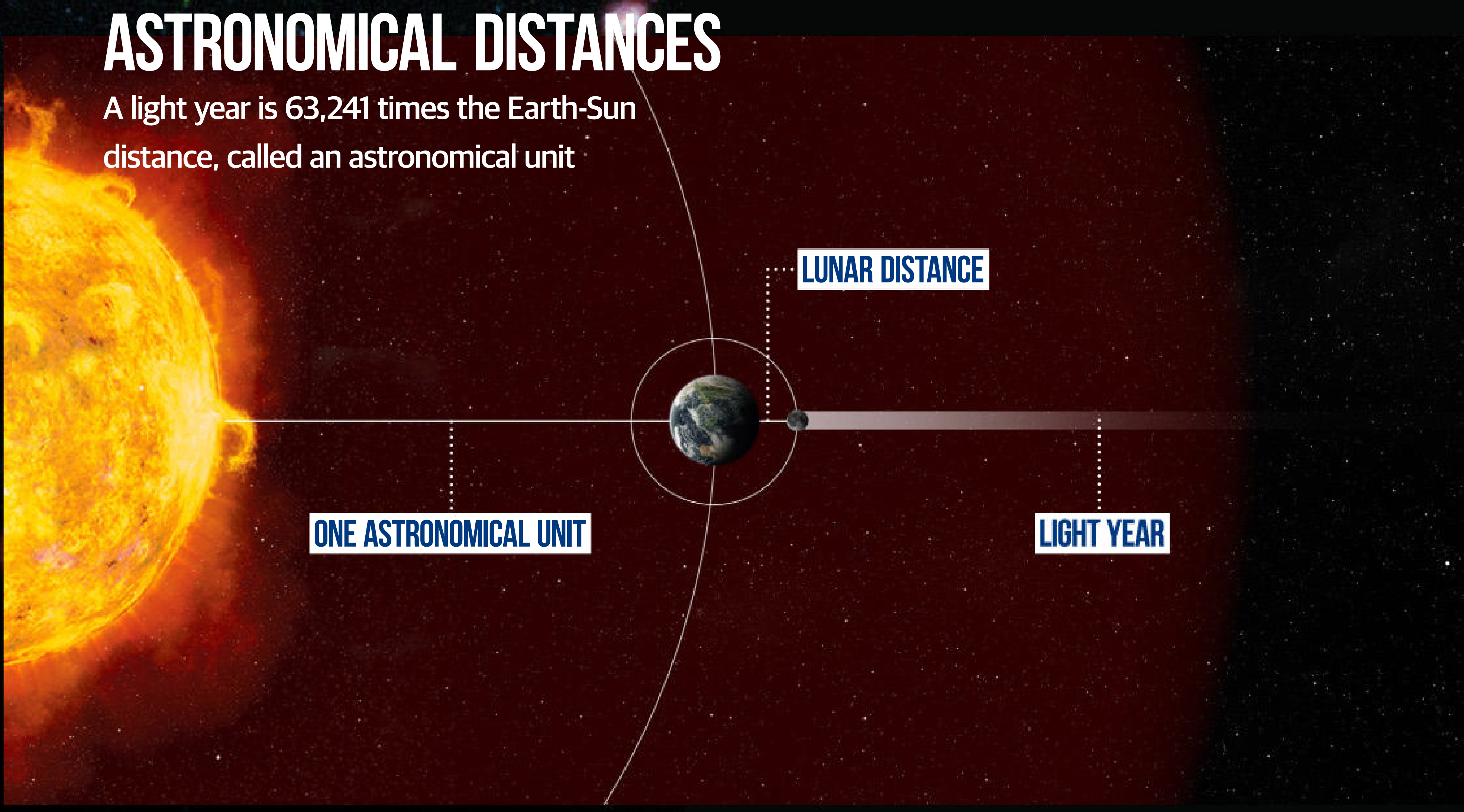
Astronomers also use parsecs as an alternative to light years. Short for parallax second, a parsec comes from the use of triangulation to determine the distances of stars. To be more specific, it's the distance to a star whose apparent position shifts by one arcsecond in the sky after Earth orbits halfway around the Sun. One parsec is equal to 3.26 light years.

The light year can also be broken down into smaller units of light hours, light minutes or light seconds. For instance, the Sun is just over eight light minutes from Earth, while the Moon is just over a light second away. Scientists use these terms when talking about communications with deep-space satellites or rovers. Because of the finite speed of light, it can take more than 20 minutes to send a signal to the Perseverance rover on Mars, and another 20 to get one back. Whether it's light years or parsecs, astronomers will continue to use both to measure distances in our expansive and grand universe.

> “WHEN YOU OBSERVE SOMETHING A LIGHT YEAR AWAY, YOU SEE IT AS IT APPEARED EXACTLY ONE YEAR AGO”

ASTRONOMICAL DISTANCES

A light year is 63,241 times the Earth-Sun distance, called an astronomical unit



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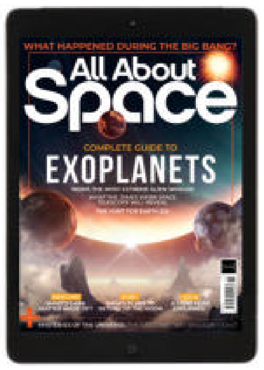
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Instant expert

WHAT IS DARK MATTER MADE OF?

The phenomena may have come from quantum bags that got squished together in the early universe

Dark matter – the mysterious, invisible substance that exerts gravity but doesn't interact with light – might be made of tiny black holes permeating the universe. And according to a new theory, those black holes might have been made from Fermi balls, quantum 'bags' of subatomic particles known as fermions that got smooshed together in dense pockets during the universe's infancy.

This theory could explain why dark matter came to dominate the universe. Scientists Ke-Pan Xie and collaborator Kiyoharu Kawana, from the Center for Theoretical Physics at Seoul National University in South Korea have devised a new scenario to explain how dark matter came to dominate the universe: in the midst of an incredible transformation when the cosmos was less than a second old, a new kind of particle got trapped, collapsing to such a small point that they transformed into black holes. Those black holes then flooded the universe, providing the heft required to explain dark matter.

Astronomers and physicists cannot explain dark matter, the mysterious substance that makes up more than 80 per cent of the mass of every large structure in the universe, from galaxies to the cosmic web itself. One intriguing possibility is that dark matter originated from black holes. After all, black holes, like dark matter, emit no light. "As a kind of non-luminous and compact object, black holes are a natural explanation for dark matter," Xie said.

Astronomers have known for a long time that normal stellar-mass black holes can't explain the universe's dark matter. That's because not nearly enough stars have formed in the history of the universe to create enough black holes to account for the known dark matter. But the earliest moments of the universe featured some pretty mind-boggling physics. Perhaps whatever was going on back then spawned trillions of smaller black holes. Those black holes could persist to the present day, potentially solving the dark matter riddle. But to explain dark matter, the theory would have to make enough black holes.

BIO

PAUL M. SUTTER

Paul Sutter is a research professor in astrophysics at the Institute for Advanced Computational Science at Stony Brook University and a guest researcher at the Flatiron Institute in New York City. He is also the author of two books: *Your Place in the Universe* and *How to Die in Space*.

> “A NEW KIND OF PARTICLE GOT TRAPPED, COLLAPSING TO SUCH A SMALL POINT THAT THEY TRANSFORMED INTO BLACK HOLES”

Below: Primordial black holes could make up dark matter, according to some theories

© Getty

THE FIRST INGREDIENT

Xie and Kawana added several ingredients to their model. They started with a very young, very hot, very dense universe. These extreme conditions allow some physical processes that do not happen in the normal conditions of the present-day universe. The first ingredient is something called a scalar field, a quantum mechanical entity that encompasses all of space. The well-known Higgs field, which gives matter its mass, is an example of one. As the universe expanded and cooled, that scalar field underwent a phase transition, transforming from one quantum state to another.

A FROTHY UNIVERSE

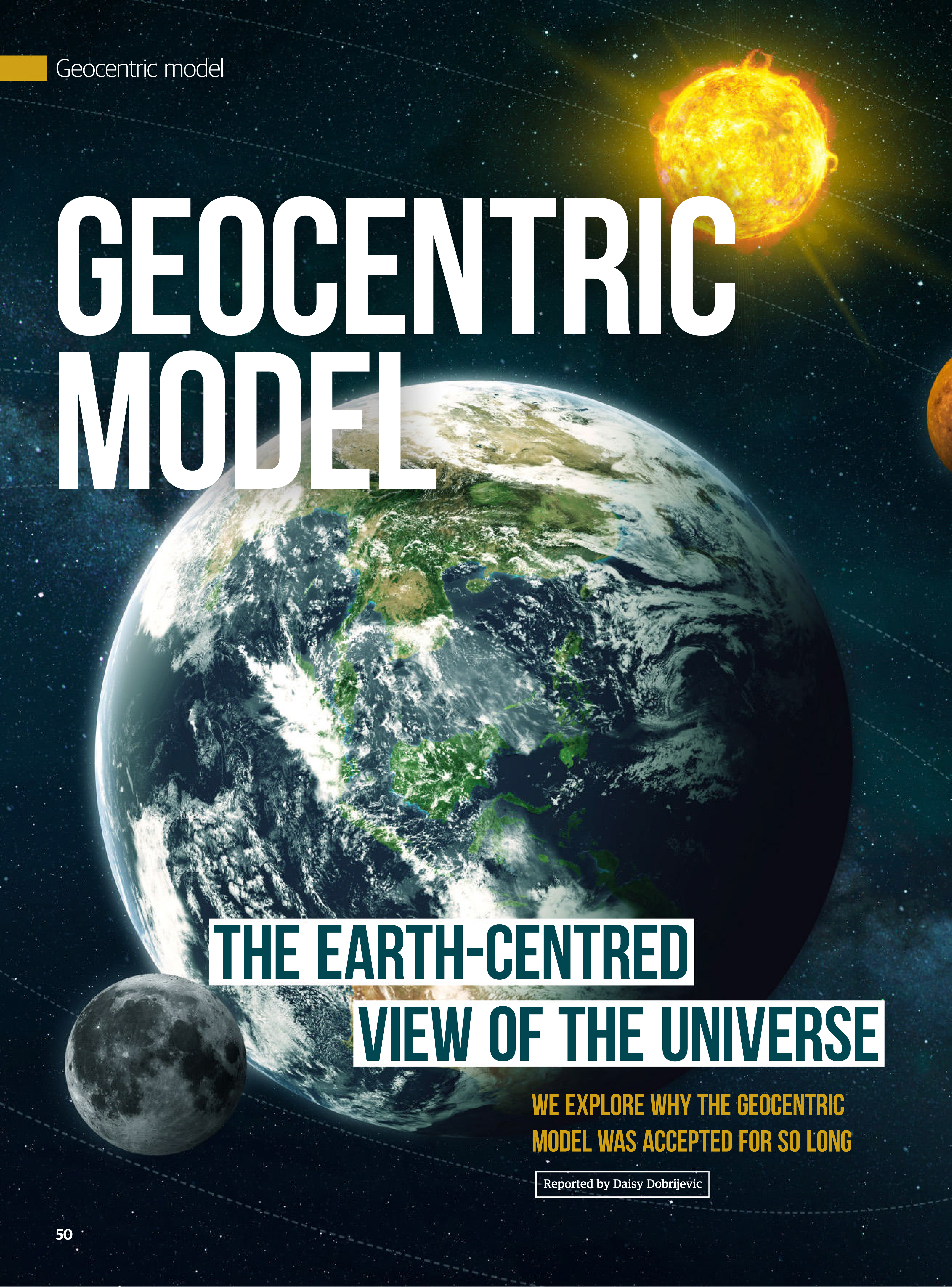
That phase transition didn’t happen all at once throughout the entire universe. Instead there were a few points where the transition began from and then spread – just as a few bubbles in a pot of boiling water merge to form bigger bubbles. “This process is called a first-order phase transition: water transfers from liquid phase into gas phase, and the latter first exists as growing bubbles,” Xie said. The new scalar field state, called the ‘ground state’, spreads out from these points like a bunch of fizzing bubbles. Eventually, the bubbles merge completely, and the scalar field finishes its transition.

THE SECOND INGREDIENT

To make primordial black holes that seed dark matter, Xie and Kawana needed another ingredient, so they added a new kind of fermion to their model. Fermions are a category of particles that make up the building blocks of the universe. For instance, the electrons, protons and neutrons that make up the atoms in your body are all fermions. In the very early universe, these fermions moved freely within the scalar field. But according to the recipe that Xie and Kawana have cooked up, these fermions couldn’t penetrate the little foaming bubbles of the new ground state of the cosmos as the phase transition proceeded.

BUBBLE TROUBLE

As the bubbles grew, fermions crowded into the remaining pockets, becoming Fermi balls. But there was an additional force, known as a Yukawa interaction, between the fermions, caused by that very same scalar field, Xie and Kawana propose. Fermions don’t like to be crammed into small volumes together, but the scalar field added an attractive force that could overwhelm that repulsion. Once the Yukawa attraction took hold, it was game over for the little Fermi balls. Wedged into little pockets of a rapidly changing universe, the clumps of fermions catastrophically collapsed, forming black holes.

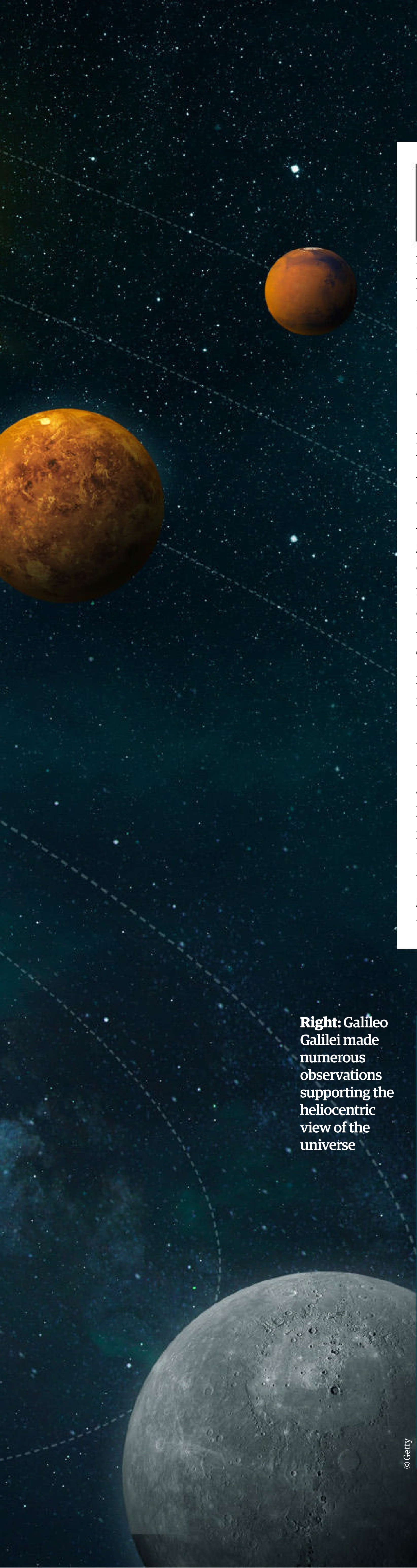


GEOCENTRIC MODEL

THE EARTH-CENTRED VIEW OF THE UNIVERSE

WE EXPLORE WHY THE GEOCENTRIC MODEL WAS ACCEPTED FOR SO LONG

Reported by Daisy Dobrijevic



Once widely accepted, the geocentric model is now the debunked theory that the Earth is the centre of the universe, with the Sun and planets revolving around it - though nevertheless, some people still believe the universe revolves around them. In a 2012 survey conducted by the National Science Foundation of 2,200 people in the United States, when asked "does the Earth go around the Sun, or does the Sun go around Earth?", a quarter answered incorrectly.

This antiquated view was once our only perspective of the cosmos. The ancient Greeks were the first to suggest a geocentric view of the universe. Eudoxus was the first to create a model of the geocentric universe in around 380 BCE. Aristotle then came up with a more detailed geocentric model, which was later refined by Claudius Ptolemaeus, also known as Ptolemy, in his treatise *Almagest*, released in the 2nd century CE. NASA states that "Ptolemy represents the epitome of knowledge of Grecian astronomy". This is reflected in the fact that the geocentric model stood the test of time and was accepted for nearly 1,500 years.

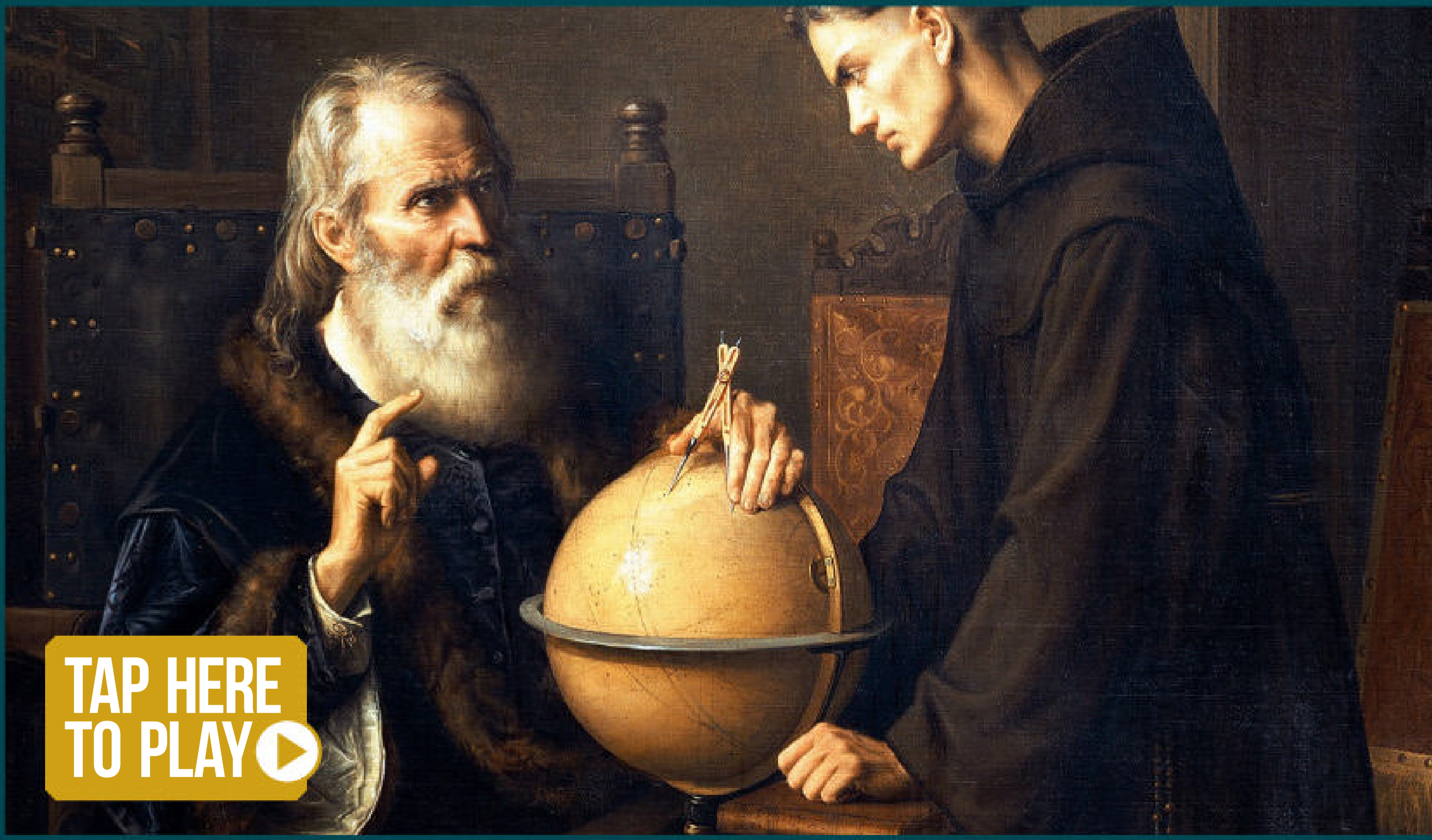
For thousands of years humans have tried to make sense of the skies above, and our understanding of the universe has evolved alongside technological advances and scientific knowledge. When gazing up at the sky from what feels like a fixed reference point and witnessing the stars and planets dance across the sky, we can understand why the ancient Greeks adopted the geocentric view of the universe. They believed that the Earth they stood on was at the centre, with the sky, or 'heavens', rotating around it in a series of layered spheres.

Ptolemy's complicated geocentric model stated that a planet moves in a small circle, known as an epicycle. The epicycle then moves around Earth in a larger circle, known as a deferent. The order of the Solar System with regards to the geocentric model is Earth - stationary and at the centre - the Moon, Mercury, Venus, the Sun, Mars, Jupiter and Saturn. As stars appeared to move much slower than the planets, they were placed in the outermost sphere, furthest away from Earth.

Despite the complexity of the model, this view was widely accepted for many years. And most of the time the model worked. It could explain why stars appear to rotate around Earth once per day and why planets move differently to stars. The geocentric model also conformed to religious beliefs at the time, as many Greek philosophers and astronomers believed that the gods created humans and the heavens are divine, so of course we must lie at the centre of it all.

Scientific models are used to test our understanding of the laws of science by predicting the behaviour of a system. If observations of a real event match predictions made by a model

> "THE ANCIENT GREEKS WERE THE FIRST TO SUGGEST A GEOCENTRIC VIEW OF THE UNIVERSE"



Right: Galileo Galilei made numerous observations supporting the heliocentric view of the universe

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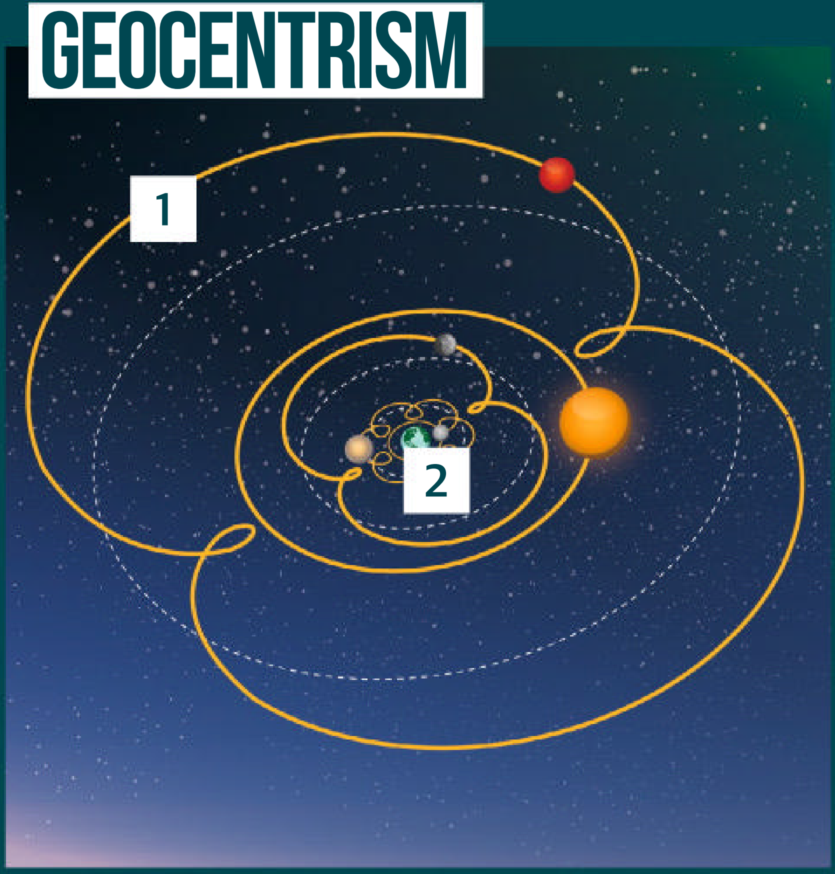
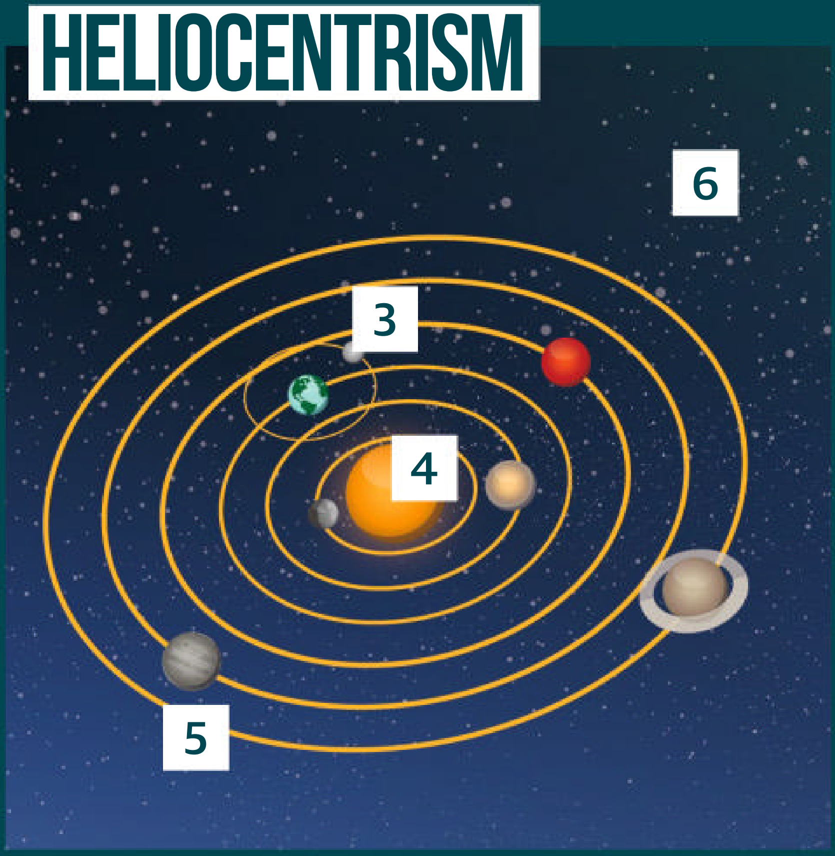
GEOCENTRISM



HELIOCENTRISM



1 ROUND AND ROUND

The concept of orbits was well understood, but theories differed. Geocentrism plotted the course of the planets from Earth's perspective over a number of years, resulting in curly orbits.

2 CENTRE OF ATTENTION

People assumed Earth was at the centre of the universe because of the Catholic Church's interpretation of scriptures. Supporters of Copernicus tried to prove this theory was incorrect.

3 MOON GAZING

By observing the moons of other planets, astronomers found evidence for the heliocentric theory, finding that Earth could both move and keep the Moon in its orbit at the same time.

4 HERE COMES THE SUN

We now know that planets circle the Sun, not Earth. By placing the Sun at the centre of the Solar System, we're able to observe that the planets move in an elliptical path around it.

5 MOONS OF JUPITER

Telescopes allowed scientists to observe the sky in great detail. As Galileo observed moons orbiting Jupiter, it disproved the idea that all celestial bodies revolved around Earth.

6 WRITTEN IN THE STARS

Geocentrism dictated that stars moved around the Earth. However, the stars are fixed. It's the rotation of Earth on its axis that makes it appear as if the stars move around us.

© NASA/JPL-Caltech

> "THOUGH MORE ACCURATE, COPERNICUS' HELIOCENTRIC MODEL STILL HAD FLAWS"

then we know the model is a good fit; however, if the observations don't match predictions made, then the model needs to be reworked. Though the geocentric model stood the test of time for nearly 1,500 years and could explain some observations of the cosmos, as well as conforming to religious beliefs, it was by no means 'simple'.

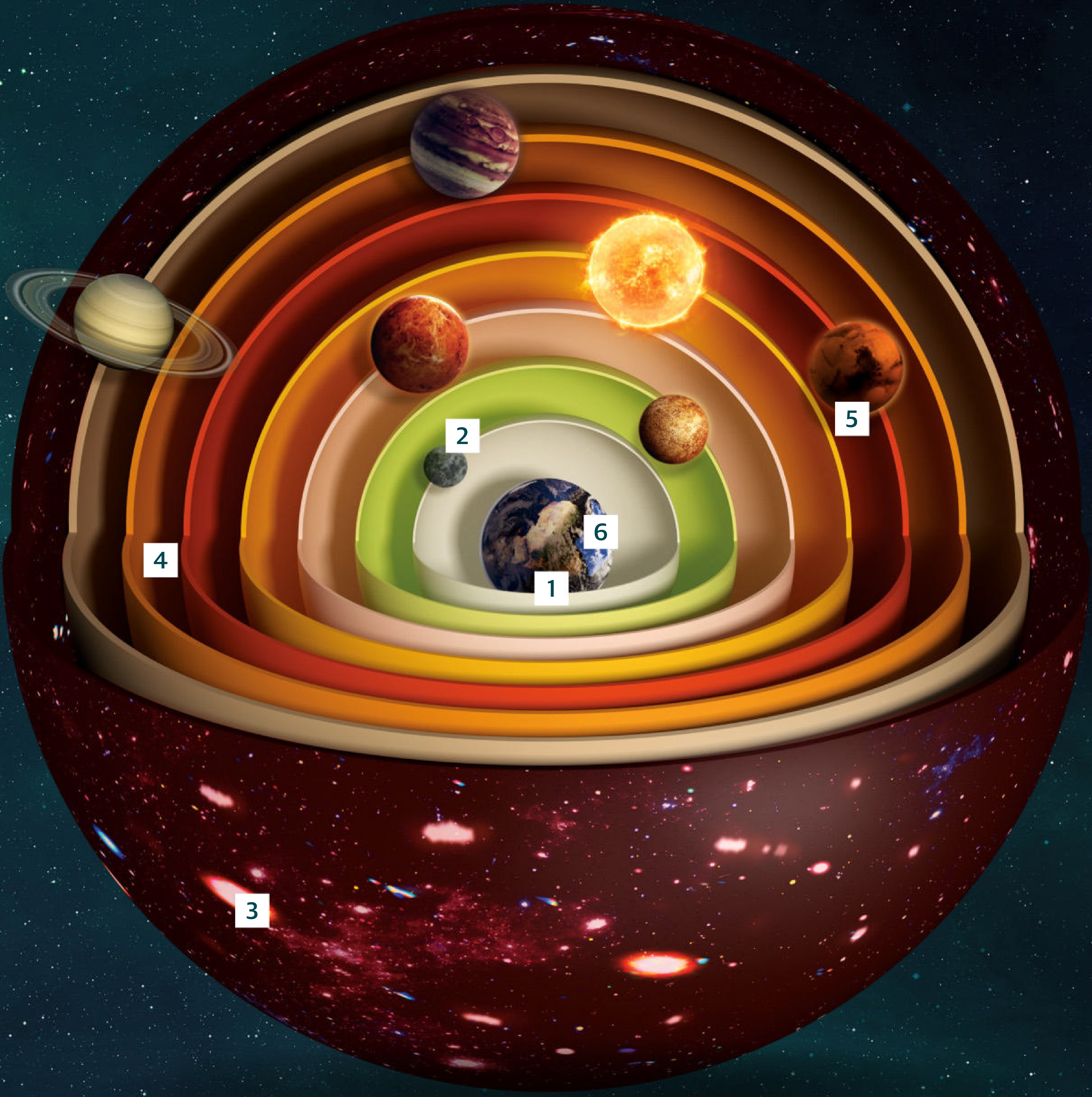
Occam's razor is a term used by scientists to help guide the creation of theoretical models. It doesn't necessarily mean to go with the simplest theory whether it's right or wrong, but instead tries to cut through the clutter to find the best theory based on the best scientific principles and knowledge at the time. At the beginning of the 16th century, Nicolaus Copernicus challenged the geocentric model and proposed that Earth and the other planets revolve around the Sun. This Sun-centred heliocentric model simplified the motion of the planets by removing the more complicated ideas of epicycles and deferents. Aware of his controversial views that we, 'creations of God', were no longer at the centre of the universe, Copernicus waited to publish his theory, *De revolutionibus orbium coelestium* (*On the Revolutions of the Heavenly Spheres*), until 1543, the year of his death.

Copernicus stated his heliocentric model could explain the apparent changes in the motion of the planets, and the Copernican Revolution began. Though more accurate than the geocentric model, Copernicus' heliocentric model still had its flaws. Copernicus suggested that Mars' retrograde motion across the sky was merely an illusion caused by Earth 'overtaking' the Red Planet as they orbit the Sun. Copernicus' heliocentric model failed to fully explain the motion of the planets as it was based on the planets moving in perfect circles. Johannes Kepler later refined the model by stating that the planets moved in elliptical orbits rather than circular. Kepler's updated model then matched observations perfectly, so the model no longer needed reworking. Despite the evidence supporting the simplified heliocentric model, the scientific community was slow to accept a shift from an Earth-centred view to a Sun-centred one. The theory had been accepted by most for over 1,500 years after all.

The main turning point for heliocentric acceptance was when Galileo Galilei gazed up at the sky with a telescope in 1610. Galileo made countless discoveries, but two in particular proved key in confirming the heliocentric view of the Solar System. First, Galileo discovered moons orbiting around Jupiter, proving objects could orbit bodies other than Earth. Secondly, he discovered that, like the Moon, Venus had phases, which further confirmed the theory that Venus – and the other planets in the Solar System – orbit the Sun.

It took almost a century for the new heliocentric model to be accepted after it was first proposed by Copernicus. Eventually, scientists couldn't reject it anymore due to the mounting scientific evidence in support of heliocentrism. The new Sun-centred model fundamentally changed our view of the universe and continues to aid our understanding of solar systems beyond our own.

Daisy Dobrijevic
Staff Writer
Daisy is **All About Space**'s Staff Writer. She previously worked for *BBC Factual* as a researcher and *BBC Sky at Night* magazine as an editorial assistant.



THE CENTRE OF IT ALL

Each planet was thought to reside in its own 'heavenly sphere'

AR SCAN HERE

1 MIDDLE EARTH

According to the geocentric model, Earth was stationary and at the centre of the universe.

2 IN ORBIT

Stars and planets all revolved around the Earth.

3 FAR STARS

Since the planets appeared to move faster than the stars, the Greeks placed them closer to Earth, with the stars located in the outermost sphere.

4 CIRCLING BACK

All objects in the sky were attached to spherical shells, and therefore followed circular paths around the Earth.

5 SEEING RED

Mars' retrograde motion was particularly problematic for Ptolemy, and his geocentric model failed to accurately predict the Red Planet's position.

6 SPEED LIMIT

The geocentric model assumed that all objects obeyed the rules of 'natural motion', meaning they orbited around Earth at the same speed.

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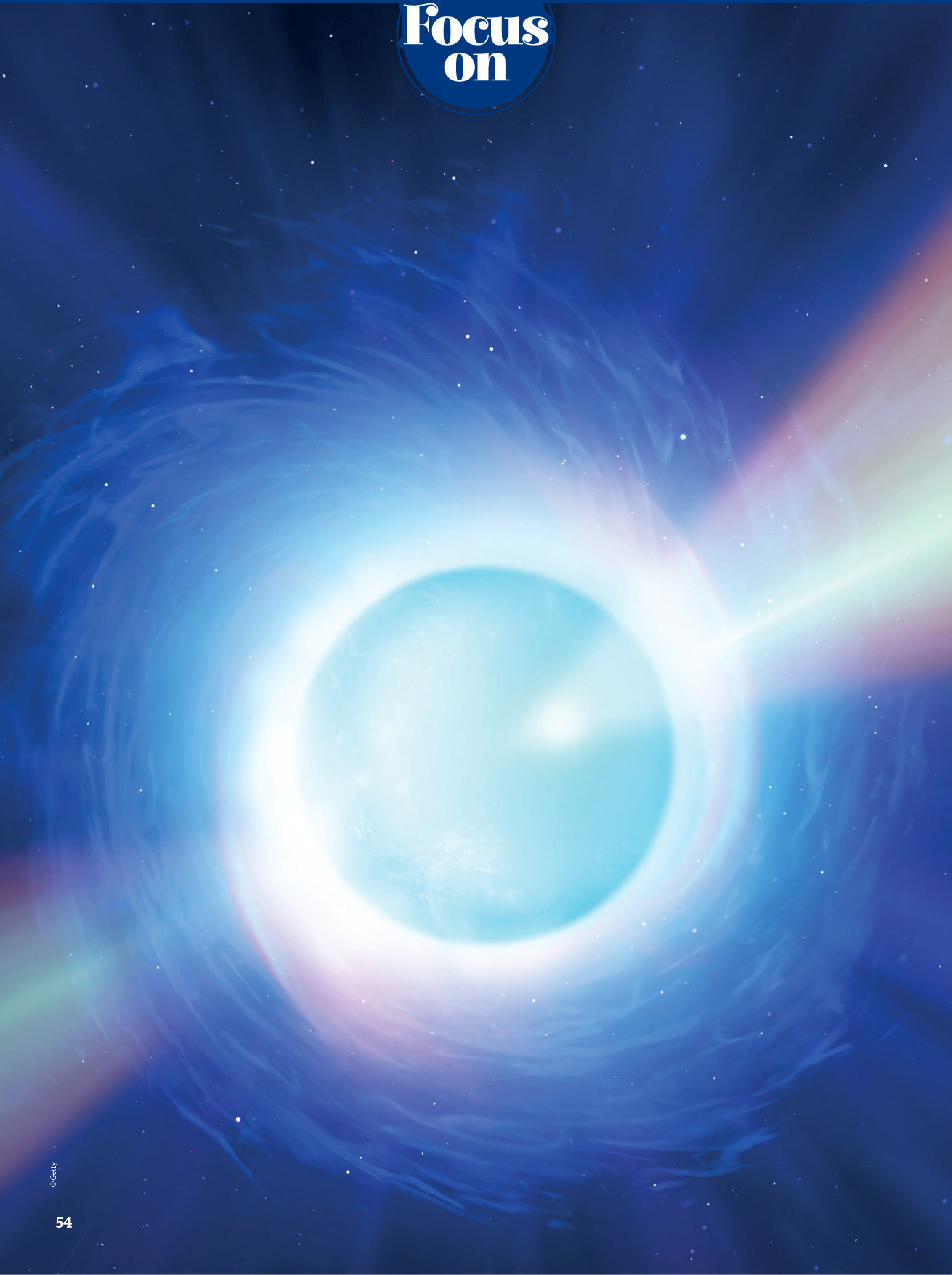

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GENERAL RELATIVITY PASSES ITS TOUGHEST TEST YET

The theory, which Albert Einstein published in 1915, remains undefeated

Reported by Mike Wall

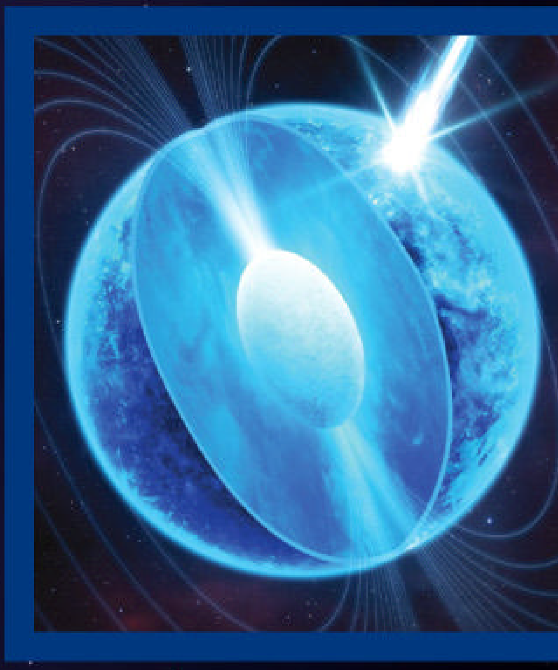
General relativity has withstood perhaps its toughest challenge to date. The theory, which Albert Einstein published in 1915, revolutionised our understanding of physics and the cosmos. It explains gravity as a consequence of space-time's flexibility: massive objects warp space-time, creating depressions around which other bodies orbit. Scientists have put general relativity to the test repeatedly over the past 106 years, trying to find situations or circumstances in which it comes up short. They haven't yet found one.

In a new study, researchers report the results of one of the most ambitious and involved challenges to general relativity ever undertaken. They analysed observations of a double-pulsar system made by seven different radio telescopes around the world from 2003 to 2019. Pulsars are a type of neutron star, superdense stellar corpses that emit powerful beams of radiation and particles from their magnetic poles. These beams are continuous, but they appear to pulse because pulsars are rotating and this light can be seen only when a pole is pointed at Earth.

The pulsar pair that the research team investigated lies about 2,400 light years from Earth. One of the pulsars spins 44 times per second, whereas the other completes one rotation every 2.8 seconds. The two objects orbit a common centre of mass once every 147 minutes, each of them moving through space at around 1 million kilometres (620,000 miles) per hour, team members said.

"Such fast orbital motion of compact objects like these - they are about 30 per cent more massive than the Sun but only about 24 kilometres [15 miles] across - allows us to test many different predictions of general relativity - seven in total!" Dick Manchester of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia's national science agency, said. And the quality matched the quantity. The study achieved levels of precision unprecedented for a general relativity test.

"Apart from gravitational waves and light propagation, our precision allows us to also measure the effect of the time dilation that makes clocks run slower in gravitational fields," Manchester said. "We even need to take Einstein's famous equation $E = mc^2$ into account when considering the effect of the electromagnetic radiation emitted by the fast-spinning pulsar on the orbital motion." All seven of the tested predictions were borne out, the study found. General relativity remains undefeated, but that doesn't mean that researchers should stop trying to find cracks in it.



Right: We only spot pulsars when their light is directed at Earth

© Tobias Roetsch

"General relativity isn't compatible with the other fundamental forces described by quantum mechanics. It's therefore important to continue to place the most stringent tests upon general relativity as possible to discover how and when the theory breaks down," Robert Ferdman, a physicist at the University of East Anglia, said.

"Finding any deviation from general relativity would constitute a major discovery that would open a window on new physics beyond our current theoretical understanding of the universe," Ferdman added. "And it may help us towards eventually discovering a unified theory of the fundamental forces of nature."

THE BIG BANG THEORY

© Getty

IT'S OUR BEST MODEL OF HOW THE UNIVERSE WORKS, BUT WHERE DID IT COME FROM?

Reported by Andrew May

People have always sought out 'big-picture' theories that explain how the universe began, what it looks like on the largest scales and how it evolves over time. In the past, such theories were often based more on human imagination than anything else. But our present best contender, the Big Bang theory, is much better than that. It's based on a mixture of observational evidence and a mathematical understanding of how space and matter behave on very large scales, and most astronomers believe it probably comes quite close to the truth.

There are two reasons we no longer need to rely on pure imagination to visualise the evolution of the universe. First there's the fact that we can actually see into the distant past. That's because light travels at a finite speed, so when a telescope shows us a galaxy a billion light years away, we're seeing it as it was a billion years ago. The second important factor is the universality of the laws of physics. This means we can study physics in laboratories here on Earth and know that exactly the same principles must apply to the rest of the universe as well.

Putting state-of-the-art observations and some very sophisticated physics together is what's given us the Big Bang theory. According to this, the universe began approximately 13.8 billion years ago as an infinitesimally tiny point, smaller than the smallest subatomic particle, with an unimaginably high density and temperature. From this minuscule beginning the universe rapidly expanded in size, eventually forming all the stars and galaxies we see today.

OBSERVING THE COSMIC MICROWAVE BACKGROUND

We can't see the Big Bang itself, but the CMB is the next best thing

COBE

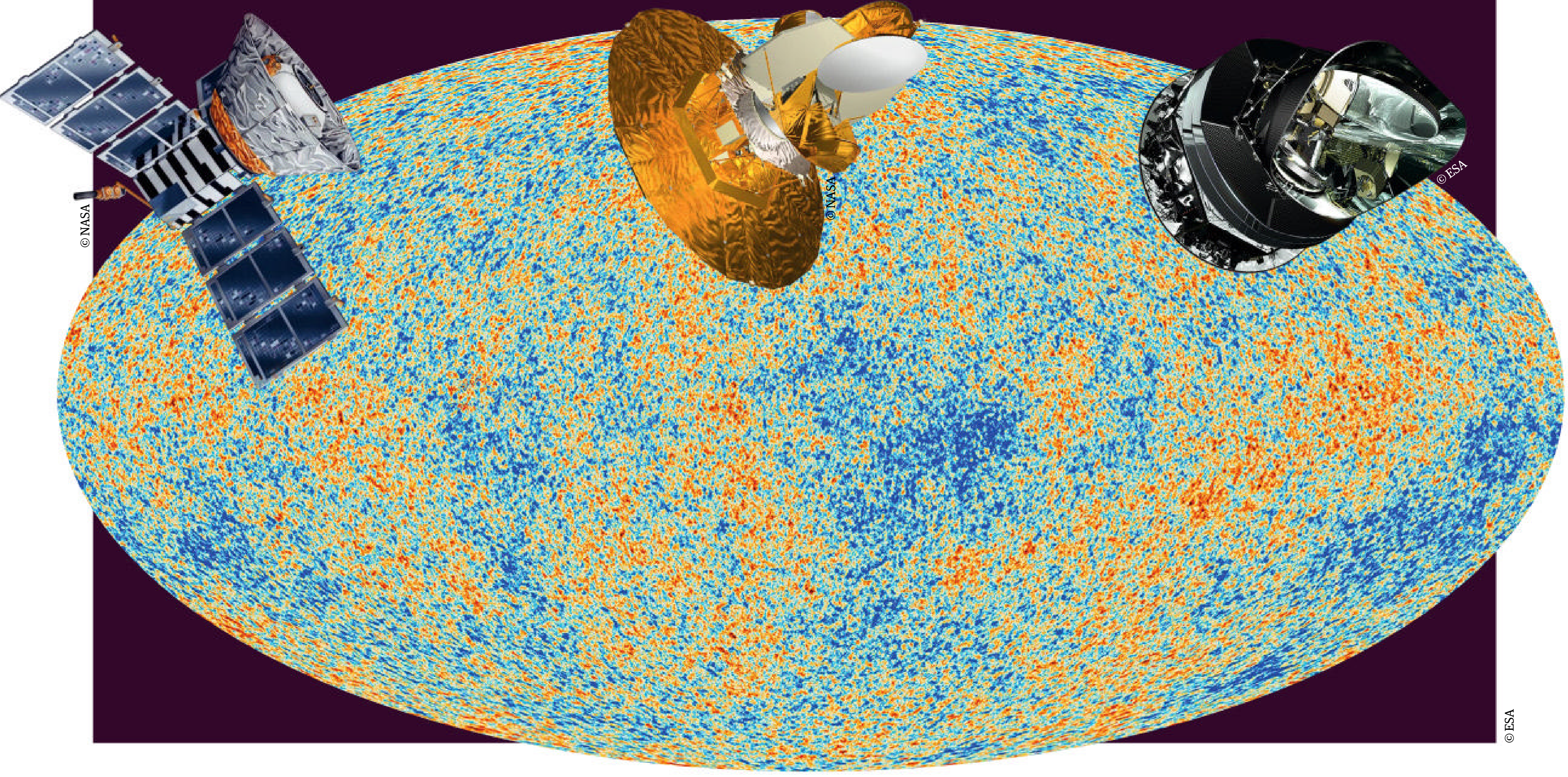
The first space mission designed to study the CMB was NASA's Cosmic Background Explorer, launched in 1989. It found the CMB is much more uniform across the sky than expected.

WMAP

A second NASA spacecraft, the Wilkinson Microwave Anisotropy Probe, mapped the CMB between 2001 and 2010, confirming the astonishing uniformity.

PLANCK

Planck was the European Space Agency's follow on to WMAP. Operating from 2009 to 2013, it remapped the CMB with higher sensitivity and resolution than its predecessor.



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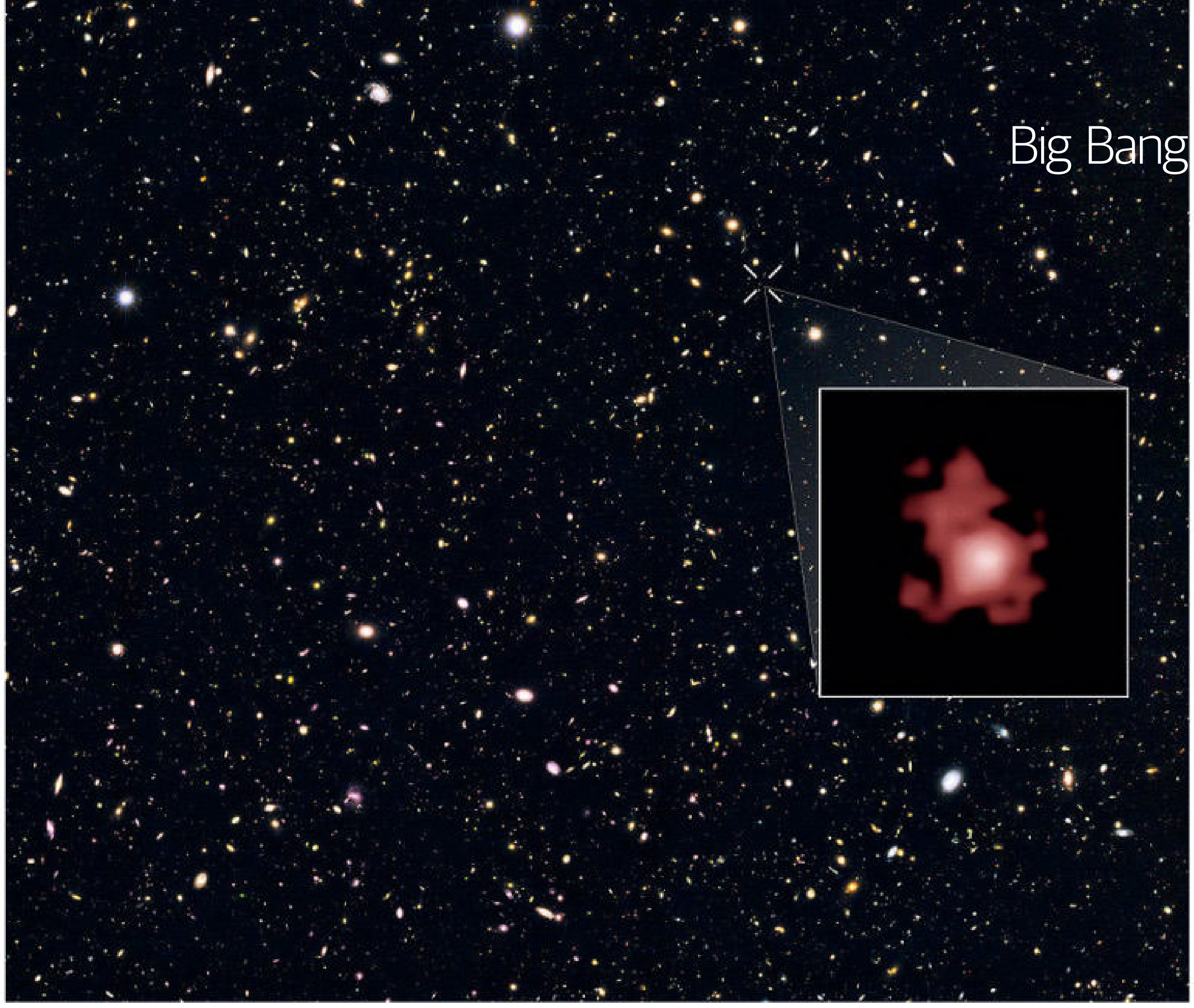
> "THE NOTION OF A BEGINNING IS REPUGNANT TO ME… I SIMPLY DO NOT BELIEVE THAT THE PRESENT ORDER OF THINGS STARTED OFF WITH A BANG"
>
> ARTHUR EDDINGTON

For many, there's something very appealing about the Big Bang theory, quite apart from its scientific veracity. With its image of a single, dramatic moment of creation, it conforms to earlier mythological and religious accounts, which gives it an air of familiarity for non-scientists. On the other hand, in its early days the theory met with opposition from some members of the scientific community, who felt instinctively that the universe should be constant and unchanging. The eminent British astronomer Arthur Eddington, for example, wrote that "the notion of a beginning is repugnant to me… I simply do not believe that the present order of things started off with a bang." It was another British scientist, Fred Hoyle, who actually coined the term 'Big Bang' to describe a theory he disagreed with. Both Eddington and Hoyle were familiar with Einstein's theory of general relativity, which describes how space and matter behave on large scales. In its earliest form, the Big Bang theory originated in the 1920s as a solution of Einstein's equations - but it wasn't the only solution. The same equations also permit a perfectly static universe, so observational evidence was needed before scientists could choose between the options.

The first step in establishing the reality of the Big Bang was the discovery that the universe is expanding. This key breakthrough was made in 1929 by Edwin Hubble, who compared two sets of data for a number of galaxies beyond our own: their distances, based on the observed brightness of individual stars in them, and the speed at which they're moving away from us, based on spectroscopic measurements. To his astonishment, he found that the further away a galaxy is, the higher its recession speed. That could mean only one thing - that the whole of space is in a state of expansion. You can think of it like a fruit cake in the oven. As the dough rises, all the raisins move further apart from each other - but in this case these raisins are galaxies.

While an expanding universe is consistent with the Big Bang theory, it doesn't necessarily require it. As counter-intuitive as it sounds, you can have a universe that's in a constant state of expansion and yet eternal and unchanging at the same time. It just needs a small amount of new matter - a few hundred atoms per year per galaxy - to be continuously created in order to maintain a constant average density as the universe expands. This 'steady-state theory', championed by Hoyle



Above: Hubble images show the distant galaxy GN-z11 as it was soon after the Big Bang

© NASA/ESA

and others, became a serious competitor to the Big Bang in the mid-20th century.

Yet the Big Bang prevailed in the end, and the steady-state picture fell by the wayside. Thanks to further observational evidence, we now know that Hoyle was wrong in assuming the universe has always looked the way it does today. Instead it's evolved over time, just as the Big Bang theory predicts. For example, Hubble images of the most distant galaxies, which we see not long after they were formed, look distinctly different than the mature galaxies we see closer to home – they're smaller and more irregular. However, that's a relatively recent discovery, and the real clincher came back in the 1960s with the discovery of the cosmic microwave background (CMB). This proved to be the kiss of death for the steady-state theory.

The CMB is sometimes described as the 'echo of the Big Bang', and if that were true then it would clearly be a great way to prove the theory correct. But the reality isn't that simple. For one thing, when Fred Hoyle put the 'bang' in Big Bang, he wasn't thinking of a literal sound, but a metaphor for the sudden onset of the universe's expansion from an initial, highly compressed state. There's no question of 'hearing' the bang, or an echo of it, but could a sufficiently powerful telescope see all the way back to that point, 13.8 billion years ago?

Unfortunately, even that isn't possible. When the universe was younger and smaller, it was also hotter, and in its earliest stages it was filled with a glowing, super-hot plasma like the Sun. That's something a telescope can never penetrate, because the plasma scatters light in the same way that clouds scatter sunlight. Just as we can't see above the cloud base, a telescope can't peer further back in time than the so-called 'surface of last scattering', around 380,000 years after the Big Bang. It's radiation from this surface – coming at us more or less uniformly from all directions – that forms the cosmic microwave background.

The CMB is an example of a phenomenon that was predicted theoretically before it was observed experimentally. Robert Dicke of Princeton University realised it would be the perfect way to verify the Big Bang theory and kill off its steady-state rival. He was busy devising an experiment to detect it when, in 1965, he heard about a problem Arno Penzias and Robert Wilson were having in an unrelated experiment at the nearby Bell Telephone Laboratories. Dicke realised that Penzias and Wilson had inadvertently detected the CMB, providing astronomers with the best evidence yet for the Big Bang.

Combining Hubble's imagery of distant galaxies with satellite measurements of the CMB, we now have pretty good observational data covering the entire history of the universe back to within 380,000 years or so of the Big Bang. But what happened before then? Although nothing can be observed directly prior to the surface of last scattering, astronomers were able to compare the CMB observations with physics theories and computer models and make a best guess. And when they did, the result wasn't anywhere near as simple as theoreticians expected.

The problem is that the CMB is simply too uniform across different parts of the sky. Scientists found it impossible to reconcile this with the idea that the universe has always been expanding at the relatively slow rate we observe today. Instead they had to assume a very brief period of cosmic inflation, during which the universe grew at a truly enormous rate.

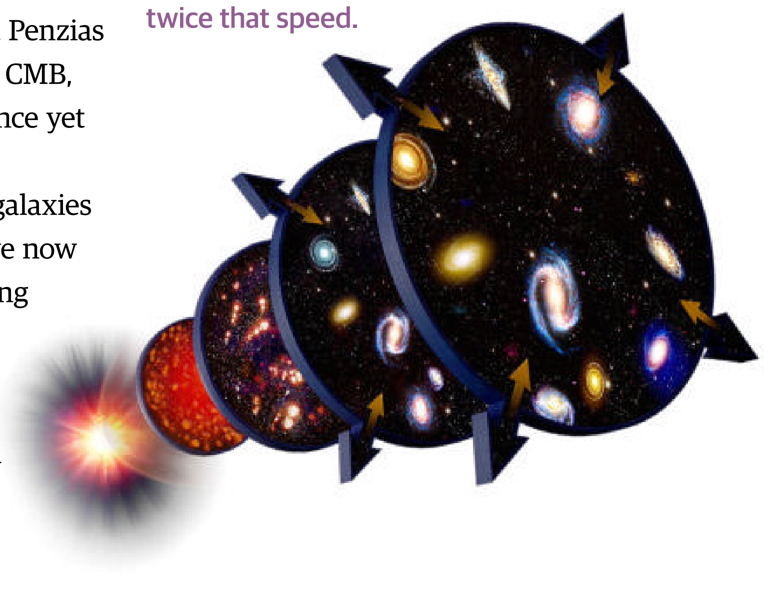
Cosmologists have worked out the exact figures for this inflation, but they're almost impossible to express in everyday terms. NASA makes a brave attempt, describing the inflationary phase as lasting "less than a trillionth of a trillionth of a second", in which time the universe expanded "from a subatomic size to a golf-ball size" at a rate "far faster than the speed of light". Einstein supporters might be taken aback by that last statement, but in fact his prohibition against faster-than-light speeds only applies to the measured velocity of one object relative to another. In this case it's the fabric of space itself that's expanding faster than light, and that's perfectly legal within the framework of relativity.

It was only after the end of the inflationary period, when the universe had settled down to a more sedate expansion rate, that conditions became 'normal' enough for matter – in the form of subatomic particles – to appear. As the expansion continued, the initially super-hot universe gradually cooled to temperatures where these particles could combine into atoms, which eventually began to form stars and galaxies.

EXPANSION VS EXPLOSION

The universe didn't start with a giant explosion – the reality is much subtler

Although the Big Bang is often described as an explosion, that's a misleading image. In an explosion, fragments are flung out from a central point into a pre-existing space. If you were at the central point, you'd see all the fragments moving away from you with roughly the same speed. But the Big Bang wasn't like that. It was an expansion of space itself – a concept that comes out of Einstein's equations of general relativity but has no counterpart in the classical physics of everyday life. It means that all the distances in the universe are stretching out at the same rate. Any two galaxies separated by distance X are receding from each other at the same speed, while a galaxy at distance 2X recedes at twice that speed.



WEBB AND THE BIG BANG

Hubble's successor will look back to the birth of galaxies

A telescope is almost like a time machine, allowing us to peer back into the distant past. With the aid of Hubble, NASA has shown us galaxies as they were many billions of years ago. Hubble's successor, the James Webb Space Telescope, has the ability to look even deeper into the past. NASA hopes it will see all the way back to when the first galaxies formed, nearly 13.6 billion years ago. And unlike Hubble, which sees mainly in the visible waveband, Webb is an infrared telescope – a big advantage when looking at very distant galaxies. The expansion of the universe means that waves emitted from them are stretched out, so light that was emitted at visible wavelengths actually reaches us in the infrared.

Right: Artist's impression of the universe coming into existence

Below: The grand design of nearby galaxies developed over time; closer to the Big Bang they're scrappier looking

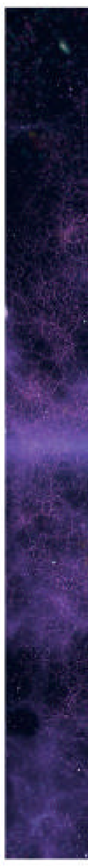
This brings us to the end of the 'Big Bang', insofar as the term refers to the birth of the universe, but the Big Bang theory goes beyond this, describing the whole evolutionary history of the universe to the present day and beyond. In this broader context, it turned out that observational astronomers had another surprise in store for the theoreticians.

In the original version of the Big Bang theory - the one that came from a solution of Einstein's general relativity equations back in the 1920s - the rate at which the universe expands isn't constant. It gradually slows down over time, pulled back by the combined gravity of all the matter in the universe. Turning this the other way around, it should be possible to calculate the total mass of the universe simply by measuring how quickly the expansion rate is slowing down. In the 1990s, a research team attempted to do exactly this by graphing expansion speed versus distance for a special class of astronomical object - Type 1a supernovae.

The result wasn't what they, or anyone else, expected. It turned out that the expansion of the universe isn't slowing down at all - it's speeding up. It was one of the most important cosmological discoveries of recent times, and it won them the Nobel Prize. It means that, on the largest scales, something is counteracting the effect of gravity, pushing galaxies apart faster and faster. As yet, no one knows what this mysterious 'something' is, but it's been given the spooky-sounding name of dark energy.

As weird as it sounds, though, dark energy doesn't contradict Einstein's theory of general relativity. It just means the particular solution that's been used so far isn't quite right. Ironically, Einstein himself may have pointed the way to the correct solution, way back before Edwin Hubble discovered that the universe is expanding. Einstein's own solution was a non-expanding static universe, but to achieve this he had to insert another factor - called the cosmological constant - into the equations. It was an idea that was abandoned after Hubble's discovery, with Einstein describing it as his biggest blunder. But a judicious choice of non-zero cosmological constant can produce an effect that, to all intents and purposes, is identical to dark energy - so Einstein may have been right after all.

Andrew May
Space science writer
Andrew holds a PhD in computational astrophysics and has written several books on space and related subjects.



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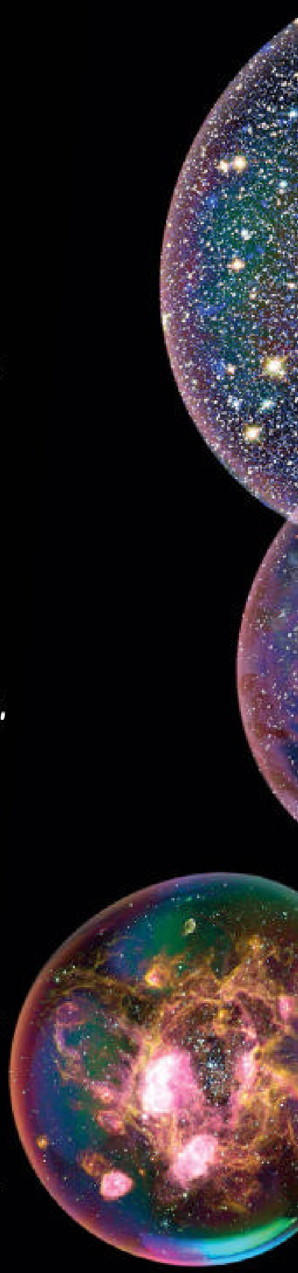
BEFORE THE BIG BANG

Our Big Bang may have been just one of countless similar events

Everything in our universe originated after the Big Bang, so there are no conceivable observations we can make that would tell us anything about what happened before then. For some scientists this makes the question of what happened before the Big Bang meaningless, but for others it's no obstacle to theoretical speculation. One of the most intriguing suggestions is the concept of eternal inflation. The current Big Bang theory requires the universe to go through an initial period of very rapid inflation, which then transitioned abruptly to the more sedate expansion we see today. But what if when our own universe dropped out of this inflationary phase it was just a tiny bubble in a vast sea of inflating space? This is the idea behind eternal inflation, which would see a whole host of other bubble universes popping up at different times in other parts of the inflationary sea.



> "IT TURNED OUT THAT THE EXPANSION OF THE UNIVERSE ISN'T SLOWING DOWN AT ALL – IT'S SPEEDING UP"

DARK ENERGY: IS IT REAL?

Science writer Brian Clegg has doubts, as he explains

© Charter Photography

The discovery of dark energy has changed our whole understanding of how the universe expands and evolves over time – but does it really exist? One person who isn't so sure is Brian Clegg, author of *Dark Matter and Dark Energy*

What's the problem with dark energy?

I have a lot of sympathy with the idea that it doesn't exist at all. The original measurement was based on a correction of the data to handle the fact that both the Milky Way and supernovae are moving, but there are huge assumptions required to do this. Some recent work, using a much larger dataset, eliminated some of these assumptions and produced no dark energy effect.

What research could be done to resolve things?

The study I mentioned looked at 740 supernovae, compared with about 110 in the original study. We need to get more data still, and more accuracy as equipment is upgraded, to get a clearer picture.

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Reported by Mike Wall

NEW ROCKY EXOPLANET HAS A YEAR LESS THAN EIGHT HOURS LONG

The iron-rich planet orbits very close to its host and exhibits scorching temperatures

> “BY MEASURING THE PRECISE FUNDAMENTAL PROPERTIES OF THE PLANET, WE CAN GET A GLIMPSE OF THE SYSTEM’S FORMATION AND EVOLUTION HISTORY” KRISTINE WEI FUN LAM

A newfound alien world could shed some light on one of the darkest and strangest corners of the exoplanet family tree. The planet, known as GJ 367b, circles a small, dim red dwarf star just 31 light years from the Sun. For perspective, our Milky Way galaxy is about 100,000 light years wide. GJ 367b is a rocky world about 70 per cent as large as Earth and 55 per cent as massive, making it one of the lightest known exoplanets. It completes one orbit every 7.7 hours and is therefore an ultra-short period planet – a mysterious and little-studied class of world.

“We already know a few of these, but their origins are currently unknown,” Kristine Wei Fun Lam of the Institute of Planetary Research at the German Aerospace Center, which is known by its German acronym DLR, said. “By measuring the precise fundamental properties of the planet, we can get a glimpse of the system’s formation and evolution history.”

The scientists discovered GJ 367b using data gathered by NASA’s Transiting Exoplanet Survey Satellite (TESS), which launched to Earth orbit in April 2018. TESS hunts for planets using the transit method, noting the tiny brightness dips caused when a world crosses its star’s face from the spacecraft’s perspective. The discovery team spotted such a dip in TESS observations of the red dwarf GJ 367, which is about half as wide as our Sun, then confirmed that the signal was caused by a transiting planet. The TESS observations also revealed GJ 367b’s super-short orbital period, as well as its size relative to its host star. The researchers characterised the planet further with the aid of the High Accuracy Radial Velocity Planet Searcher (HARPS), an instrument installed on the European Southern Observatory’s 3.6-metre Telescope in Chile.

The HARPS measurements showed how much GJ 367b was tugging on its host star, allowing the scientists to calculate the exoplanet’s mass. Combining the various observations enabled the astronomers to determine GJ 367b’s density, which is higher than Earth’s. “The high density indicates the planet is dominated by an iron core,” DLR’s Szilárd Csizmadia said. “These properties are similar to those of Mercury, with its disproportionately large iron and nickel core that differentiates it from other terrestrial bodies in the Solar System.”

GJ 367b is not a good candidate to harbour life as we know it. Because of its extreme proximity to its host star, the planet is blasted by stellar radiation, absorbing about 500 times the amount that Earth receives from the Sun. If GJ 367b ever had a substantial atmosphere, it was almost certainly lost to space long ago. And the planet is likely tidally locked, always showing the same face to its host star, with temperatures reaching up to 1,500 degrees Celsius (2,700 degrees Fahrenheit) on its scorching dayside.

It’s unclear how GJ 367b formed, but a few different scenarios could explain its structure and composition. For example, it’s possible that the planet formed from oddly iron-rich building blocks. Or GJ 367b may be the remnant of a larger planet, much of whose mass was stripped away by stellar radiation or a giant impact.

GJ 367b’s weirdness is very intriguing to planetary scientists and astrophysicists. “Understanding how these planets get so close to their host stars is a bit of a detective story,” TESS team member Natalia Guerrero, an astrophysics PhD student at the University of Florida, said. “How did it move close in? Was this process peaceful or violent? Hopefully this system will give us a little more insight.” That insight may indeed come in the not-too-distant future. Given GJ 367’s relative proximity to Earth, astronomers should be able to study it using a variety of instruments going forward.

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MYSTERIES OF THE UNIVERSE

THE PLANET THAT SHOULDN'T EXIST

This two-star system with a mass six times that of our Sun emits extreme radiation, yet somehow a planet has still managed to form

Reported by David Crookes

You would think that a planet which is 11 times as massive as Jupiter - itself the largest planet in the Solar System - would be very easy to spot. But that's not always the case. If the method of discovery isn't quite good enough, then it's always going to be much more difficult to find something, even if it's hiding in plain sight. This can lead to theories that turn out to be incorrect, and that's what recently came to light when an exoplanet suddenly popped into view during a wide-ranging sky survey. Before this happened, some scientists firmly believed that planets couldn't form around stars that were more than three times as big as the Sun. But that was primarily because no one had ever found any that did. They have now.

Late in 2021, astronomers simply couldn't believe their eyes. The European Southern Observatory's Very Large Telescope (VLT) had captured an image of a planet orbiting the two-star system b Centauri. It looked huge, and indeed it was, for this exoplanet has

b CENTAURI b BY NUMBERS

11x

more massive than Jupiter

18,000

Temperature, in degrees Celsius, of the main star b Centauri A

325

Distance from Earth to b Centauri in light years

560

Number of astronomical units between b Centauri b and its two stars

HIP 71865

Another name for the b Centauri two-star system

6x

The two-star system is more massive than the Sun

ZERO

Number of planets besides b Centauri b to be found around a star more than three times as massive as the Sun

20

Years since b Centauri b was first spotted

0.10-0.17%

Planet-to-star mass ratio

been shown to be a whopping 11 times as massive as Jupiter. It's also a world that, in theory, still shouldn't exist because the environment in that neck of the woods is rather hostile.

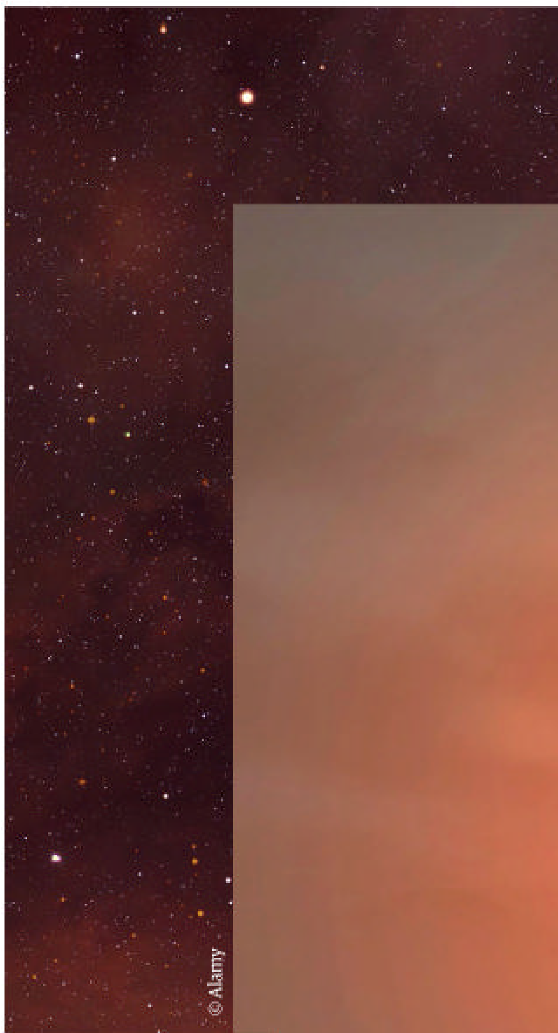
Prior to using the VLT, the only detailed studies performed for planets around large stars were carried out using a technique called the Doppler method. This indirect approach for finding extrasolar planets and brown dwarfs works on the principle that orbiting planets have a gravitational influence that causes stars to wobble. The bigger the orbiting body, the bigger the effect it will have on the star. As it wobbles, the star's emitted light waves compress and stretch. Astronomers see this as a change in colour of the light, and it enables them to work out the motion and properties of a celestial body and the star it orbits – all without actually seeing the exoplanet.

"The Doppler technique is very efficient for detecting planets in small orbits around stars," explains Professor Markus Janson, an astronomer at Stockholm University in Sweden. "The previous Doppler studies found that gas giants are very common for stars about two times heavier than the Sun, but that they're very rare for even heavier stars. A possible interpretation of this is that maybe planets simply cannot form around such massive stars." Janson now knows for sure that this is incorrect. After all, it was he who led a new study of the b Centauri two-star system as part of a direct imaging search for planets around very massive stars. The search, called the B-star Exoplanet Abundance Study (BEAST), was pursued because it tackled a shortcoming of the previous method.

"The Doppler technique is very sensitive to planets in small orbits, but it's not sensitive to all planets in very wide orbits," Janson tells **All About Space**. "If there's a population of planets that form at wide separations around massive stars, it would be missed in those surveys. BEAST is sensitive to wide-orbit planets, which is why we started it." The astronomers included b Centauri as one of 85 B-type stars that they wanted to take a closer look at. These stars are extremely luminous and blue, and they are between two and 16 times the mass of the Sun. "The main idea of the study was to check whether or not very massive stars can form and host planets around them," Janson continues. "The b Centauri system was among the first batch of targets that we could check for, and confirm, planets. To find a planet so early on in the survey – and to find it around one of the most massive stars in our sample – was a real surprise."

The b Centauri two-star system, located in the Centaurus constellation, is about 15 million years old. That makes it much younger than our

Right: Nearby Proxima Centauri is a red dwarf star known to host at least one planet



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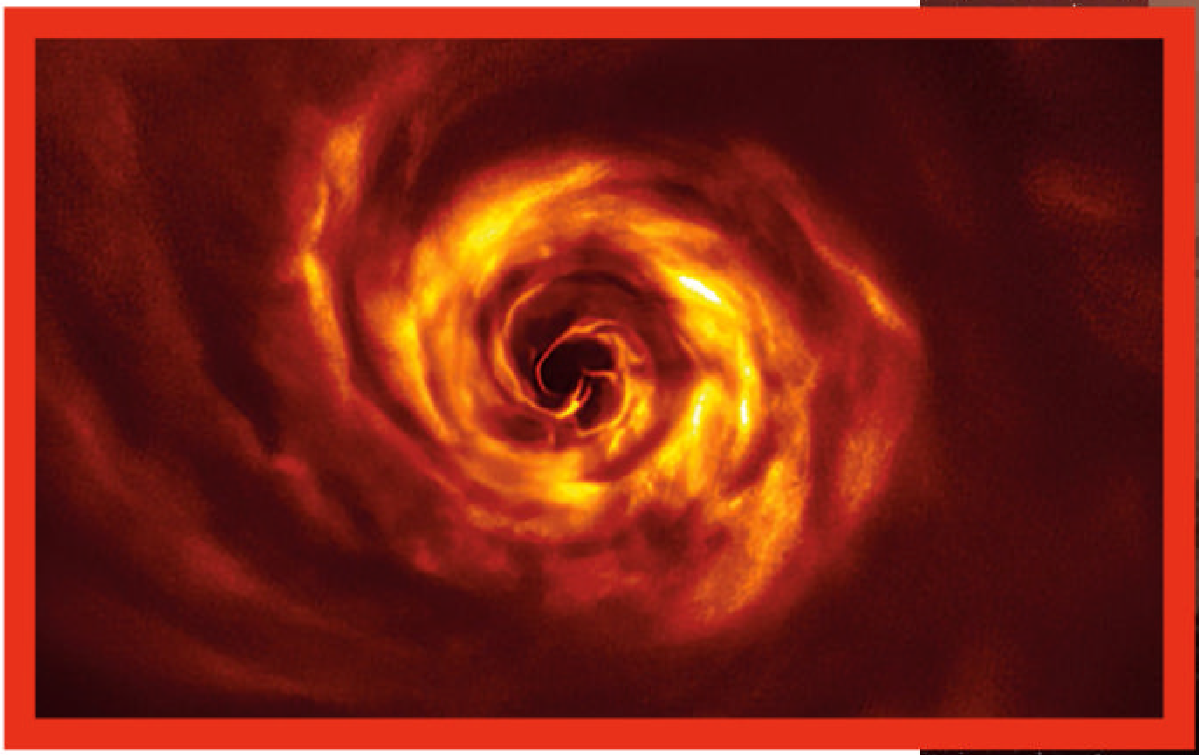
Below: The VLT's SPHERE instrument has been making many breakthroughs. In 2020 it captured the first-ever image of two planets orbiting a star like our Sun, as well as signs of a planetary system being born



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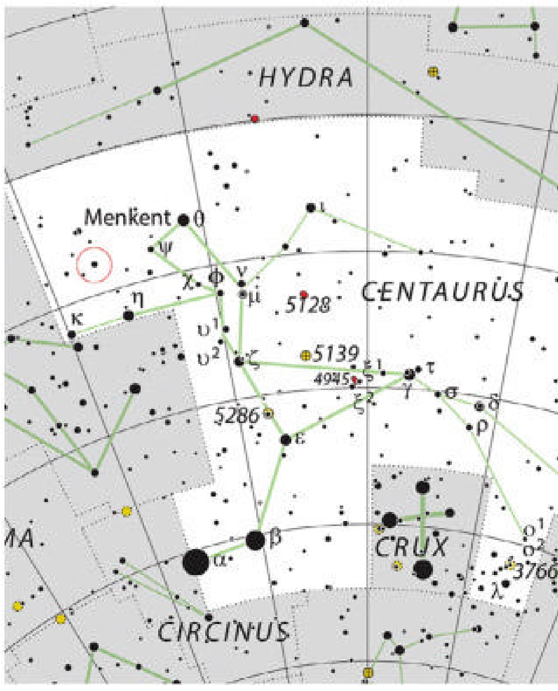
Sun, which has burned for more than 4.5 million years. Still, it's easily seen in the night sky. "Unless you live quite far north on Earth, you can see the constellation of Centaurus in the night sky during spring and summer," Janson says. "The star system b Centauri can also be easily seen with the unaided eye in that constellation, if the sky is reasonably dark."

So why was the system's planet, called b Centauri b, missed by previous methods. One of the biggest reasons is that this exoplanet is 325 light years away in an orbit that's so far out, it's equivalent to 100 times the distance Jupiter orbits the Sun. There was no chance of the Doppler method finding an exoplanet this far from a star. "The orbit is about 100 times wider than Jupiter's orbit around the Sun, and it's relatively circular, which is opposed to being highly elliptical," affirms Janson of a planetary orbit that's among the widest ever known.

Yet the planet is intriguing astronomers for reasons other than it simply being found. It's already throwing up a host of mysteries about how it formed, primarily because it's in an environment that's completely different to anything experienced in our Solar System. Not only is it the hottest and largest planet-hosting system known to date – its main star is three times as hot as the Sun, and combined the two stars are six to ten times heftier than the Sun – it's emitting large amounts of ultraviolet (UV) and X-ray radiation. Such heat and the large mass of the star would have a strong



Right: The b Centauri system, circled in red, is in the constellation of Centaurus; the stars are visible to the naked eye

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"THE MAIN IDEA OF THE STUDY WAS TO CHECK WHETHER OR NOT VERY MASSIVE STARS CAN FORM AND HOST PLANETS AROUND THEM" MARKUS JANSON

TAP HERE TO PLAY

> "INTENSE EMISSIONS WOULD HAVE HAD A HUGE IMPACT BACK WHEN THE PLANET FORMED BECAUSE IT CREATES A HOSTILE ENVIRONMENT"
>
> MARKUS JANSON

Left: The VLT is an array of four telescopes, each with a main mirror 8.2 metres (26.9 feet) in diameter. They can observe individually or collectively

TAP HERE TO PLAY

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impact on the surrounding gas, and that means planets shouldn't be able to form.

"We know b Centauri b is a gas giant about 11 times heavier than Jupiter - a class sometimes referred to as super-Jupiters," Janson explains. "But the intense UV and X-ray emissions would have had a huge impact back when the planet formed because it creates a hostile environment. Newly formed stars have discs of ice and dust and gas around them, and it's from this material that planets form. But UV and X-ray radiation have a detrimental effect on such discs, destroying molecules and forcing them out of the system."

The theory is that such high-energy radiation evaporates material. Yet here we have b Centauri b, a particularly large planet. "The fact we are seeing a planet in such a seemingly hostile environment implies that planet formation is a very robust process which can operate in more diverse environments than we had imagined," Janson says. But what's key to the planet's survival? It may be due to its trajectory around the two-star system.

As noted, b Centauri b is a wide-orbit giant planet. You'd have to travel from Earth to the Sun 560 times before you've covered the distance between the exoplanet and its star. But that could have worked in its favour. "Most likely, the wide orbit of the planet was a key aspect that allowed it to form," says Janson. "At such a large distance from the star, the impact of the high-energy radiation would be somewhat diminished and the disc could survive for longer."

Quite how it formed is still unknown, though. One possibility is that the planet didn't form in its present location. It may have formed elsewhere

© NASA/ESA

Above: Just like Jupiter, b Centauri b is a gas giant

IMAGING A PREVIOUSLY UNSEEN GIANT PLANET

How b Centauri b was directly observed by the European Southern Observatory's Very Large Telescope

1 THE NEWLY DISCOVERED PLANET

The planet can be seen here as a bright dot. While it's pictured small, it's actually 11 times as massive as Jupiter, which is itself 2.5 times more massive than all the other planets in the Solar System combined.

2 BACKGROUND STAR

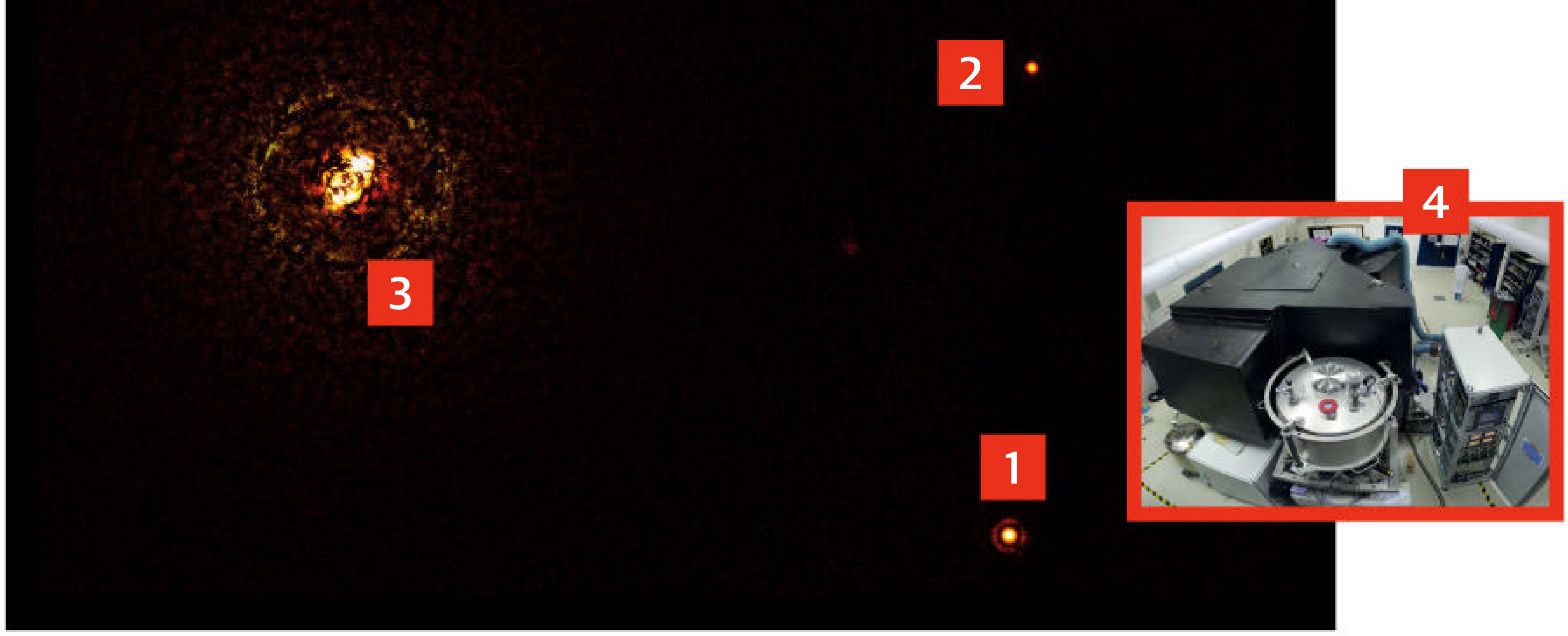
It's not easy spotting planets, especially when there are background stars to filter out. Here the background star looks similar to the planet, but when astronomers take multiple images at different times, the planet's movement makes it stand out.

3 THE BINARY STAR SYSTEM

Just as the Sun is 11 times wider than Jupiter, the b Centauri two-star system is more prominent in this image than its orbiting planet. With a mass six times that of the Sun, you'd expect it to be.

4 GETTING A CLEAR IMAGE

The SPHERE instrument on the VLT was used to take the image. A specialised telegraphic attachment called a coronagraph blocked out the direct light from the star so that the objects around it wouldn't be obscured by the glare.



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THREE POTENTIAL EXPLANATIONS

How did it form in such challenging conditions?

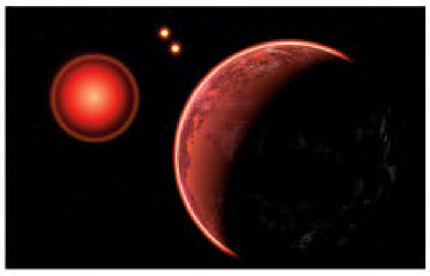
PLANET FORMATION IS ROBUST

These theories look to account for the intense amounts of radiation emitted by the huge main star in the system, since this creates an environment in which planets shouldn't really be able to form. But maybe planets can form and flourish in such environments. Perhaps, as Janson says, planet formation is possible in "more diverse environments than we had imagined".

© Getty

FORMED CLOSE AND BOOTED OUT

A standard theory for the formation of gas giants is core accretion. An icy core forms from collisions between planetesimals, then gas in the protoplanetary disc is attracted. This could have happened with b Centauri b, forming close to the binary star before being forced by gravitational interactions to move to its present location.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GRAVITATIONAL INSTABILITY

Another theory suggests the core accretion happened close to its present location. This supposes that the planet hasn't moved. The mass of the protoplanetary disc will have been so great that part of it collapsed in on itself, creating a planet that orbits the star. It's an unusual way to form a gas giant, but it's possible this could happen.

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and found its way to the b Centauri system. "We cannot exclude that the planet formed somewhere else than where we see it today," Janson says. "It's possible for planets to shift across large distances in the discs they form in, and it's even possible for planets to 'jump' from one star to another if two stellar systems happen to pass very close by each other. However, in most cases where such events take place, the orbit becomes highly elliptical, and usually not near-circular as with b Centauri b.

"There's also no indication that the b Centauri system would have passed particularly near to any other stellar systems in the past. The most likely scenario is that the planet formed relatively close to where we see it." If this is the case, though, it still begs the question of how it could have survived the environment created by the hot two-star system.

According to Janson, the more likely explanation is that it formed via gravitational instability. "Sometimes a cloud of gas in space can become gravitationally unstable," he says. "This means that it collapses under its own weight and falls together into a compact object. "It has long been hypothesised that if such a gas collapse happened in a disc around a star, it could form a planet. We have a lot of evidence to suggest that most gas giant planets don't form like that, but instead form when solids in the disc gradually build up bigger and bigger systems, which eventually become so massive that they pull in a thick gas atmosphere around them. But that doesn't mean that formation through gravitational instability couldn't happen in some instances. Perhaps that could be the case in the b Centauri system."

It certainly adds to the intrigue, and the task now is for astronomers to continue observing the exoplanet and the two-star system. In this instance, most of the insights were gained from the Spectro-Polarimetric High-contrast Exoplanet REsearch (SPHERE) instrument mounted on the VLT, which is situated in Chile. It was capable of taking a direct image of b Centauri b, but it wasn't actually the first time it had been captured.

When the team looked back over supplementary data from the archives, they saw the exoplanet had been imaged more than 20 years ago by the ESO 3.6-metre Telescope, also in Chile. This telescope hosts the exoplanet hunter HARPS (High Accuracy Radial velocity Planet Searcher), yet no one had figured out what had been captured back then.

The next step is going to be making use of the Extremely Large Telescope (ELT), which is still under construction but will have 256 times the light-gathering area of the Hubble Space Telescope. It's based on top of Cerro Armazones in the Atacama Desert in northern Chile, and first light is being planned for 2027. "We hope to find more planets around massive stars so we can say something about their statistical properties," says Janson. "We also hope to characterise them with spectroscopy to figure out what they're made of, which would also give us clues about the details of how they formed.

"With the ELT we could detect much smaller planets, and in an even wider range of systems. This will hopefully help us solve how planets form, and also to examine aspects such as in which kinds of systems life could arise and survive," he concludes.

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

> "MOST LIKELY, THE WIDE ORBIT OF THE PLANET WAS A KEY ASPECT THAT ALLOWED IT TO FORM"
>
> MARKUS JANSON

Right: Artist's concept of nearby Proxima Centauri b depicted as a massive rocky world

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> "MORE DESIGN CHANGES TO THE PROGRAM ARE ALREADY UNDERWAY, TO START FLYING DURING THE NINTH MISSION OF THE SLS"

NASA ORDERS MORE MEGABOOSTERS FOR MOON MISSIONS

The new contract will support Space Launch System (SLS) missions through Artemis 9

Reported by Elizabeth Howell

NASA just awarded a contract worth $3.19 billion (£2.36 billion) to build rocket boosters for Artemis missions through 2031. The new award builds on a previous 2020 contract authorising Northrop Grumman to prepare for production and building of twin boosters for the next six SLS megarocket flights following Artemis 3, which will bring the program through Artemis 9. The SLS - which will make its first uncrewed flight in 2022 - is tasked with sending crews across the Solar System, starting with missions to lunar orbit, the lunar surface or the planned Lunar Gateway space station. The first crewed orbital flight is expected in 2024 and the first landing mission in 2025. NASA's contract indicates the award will be beneficial in helping the agency plan and grow the Artemis program to meet future needs.

"The contract allows NASA to work with Northrop Grumman to not only build the boosters for upcoming missions, but also to evolve and improve the boosters for future flights," said Bruce Tiller, SLS booster manager at NASA's Marshall Space Flight Center.

The SLS booster technology is based upon the solid rocket boosters used to assist NASA's Space Shuttle during launches. Solid rocket boosters were used during 135 Space Shuttle missions between 1981 and 2011. The manufacturer was initially Thiokol, later called Orbital ATK, and Northrop Grumman now has the technology thanks to a series of company mergers in the last decade. The SLS boosters are designed to be one-time use - not reusable, as the Space Shuttle program asked for - and include a fifth segment over the shuttle's four. Northrop Grumman's statement about the new contract indicates more design changes to the program are already underway, to start flying during the ninth mission of the SLS.

"The new boosters will replace the steel cases used for the Space Shuttle with a weight-saving composite case and upgraded structures, electronic thrust vector control systems and propellant materials to address obsolescence," the company stated. "This improved design additionally provides process simplification, improved interface and streamlined ground processing, leading to greater productivity and efficiency."

Orbital ATK, a predecessor entity to Northrop Grumman, began test firings of the booster system in 2009, following years of development. The SLS booster was originally slated to be the first stage of the Ares rocket under a cancelled Moon-to-Mars program known as Constellation, but the technology was eventually repurposed for the SLS. Northrop Grumman has been the lead manufacturer for SLS booster development since acquiring Orbital ATK under an agreement announced in 2017.

This new announcement arises from a nearly $50 million (£37 million) NASA letter contract in June 2020 to provide funding and authorisation for future Northrop Grumman booster orders. It authorises production and operation for boosters supporting the missions Artemis 4 through 8, along with evaluation of a new booster design to fly on Artemis 9.

As of December 2021, Northrop Grumman says it has finished booster production on Artemis 2 and that all segments for the Artemis 3 boosters have been cast with propellant. Artemis 4 segments started casting in November. Northrop Grumman is also executing other NASA contracts in support of Moon missions. This includes building the abort motor and attitude control motor for the Orion spacecraft's launch abort system and building a habitat and logistics outpost module for Gateway.

Right: The powerful boosters will take humans back to our natural satellite

x2 images © NASA

ASK Space

Our experts answer your questions

© NASA

GALAXIES

Can galaxies die?

It very much depends on how you define a galaxy being alive! A common definition is that a galaxy is alive if it's forming new stars, and by that definition, galaxies can - and often do - die. Any galaxy we see that is very red in colour has mostly stopped forming stars - the blue stars that formed with the red ones die off the quickest, leaving the red ones behind.

There are many reasons a galaxy might stop forming stars - maybe it's out of gas, needed to form new stars. Maybe the gas is there, but simply too hot to be able to cool and collapse down into a star. The end result is the same in both cases: no new stars. On the other hand, you could choose a more lenient definition: if it exists, it's alive. To die would thus be to have the galaxy disappear entirely.

The closest we get is if the galaxy were to merge with another galaxy. It would then build a new galaxy with its companion, marking the end of its previous existence - though it hasn't disappeared; it's had all of its pieces folded, like clay, into a new form.

© Jennifer Manna

Dr Jillian M. Scudder, department of physics and astronomy, Oberlin College and Conservatory

Above: Galactic mergers can give rise to new galaxies

STARS

What's the difference between a globular cluster and open cluster?

Globular clusters are much more massive, and they are usually much older. Open clusters have comparatively fewer stars and are comparatively young. Well, young in astronomical terms that is... There is pretty much nothing in between these two extremes, and the reason for this is as interesting as the question itself. Globular clusters are relics of an ancient time when the universe had more gas to fuel intense star formation. These conditions no longer exist (or are very rare) in the present universe. Forming a new globular cluster would be a feat, and thus new star clusters are comparatively smaller. There are no old open clusters simply because they have not survived billions of years of interactions with their host galaxies and environment; instead they have been split apart by gravitational interactions, and their stars now populate their host galaxies. Globular clusters survived their cosmic journey because they were massive enough to hold onto their stars for billions of years.

Dr Caroline Foster, University of Sydney

Right: Globular cluster NGC 6380 lies approximately 35,000 light years from Earth in the constellation of Scorpius

© ESA/Hubble & NASA

Did you know?

Omega Centauri is the largest known globular cluster in the Milky Way at around 150 light years across.

EARTH

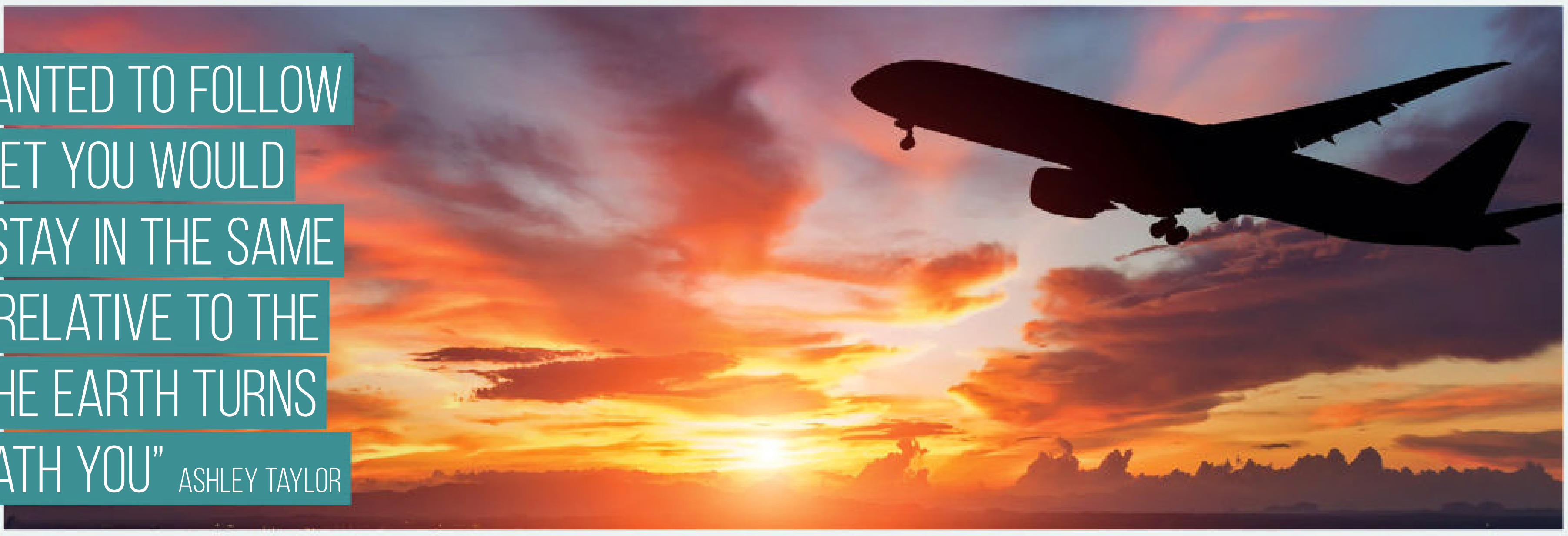
How many sunsets could you see on Earth in one day?

Hypothetically, if you started at a location on Earth where the Sun was setting and travelled westward at the speed Earth turned to the east, then you could remain in a state of constant sunset. In 2014, an ex-NATO pilot, a photographer and a filmmaker attempted to follow the sunset around the globe, through all 24 time zones, as a publicity campaign. They didn't quite make it, but their effort provides a look into the science of sunset chasing.

If you wanted to follow the sunrise or sunset you would need to stay in the same position relative to the Sun as the Earth turns underneath you. To do that at the equator, where the planet is at its maximum circumference around its axis of rotation, you'd have to fly at 1,609 kilometres (1,000 miles) per hour. That's extremely fast; most commercial aeroplanes fly at a cruising speed of 740 to 925 kilometres (460 to 575 miles) per hour, whereas the US Navy's Blue Angels air display team flies at a maximum speed of 1,126 kilometres (700 miles) per hour during air shows.

Concorde jets, which could reach a speed of 2,179 kilometres (1,354 miles) per hour, could have kept up with Earth's rotation – even at the equator – but the jets stopped flying in 2003. They may not have chased the sunset, but Concorde's flights from London to Dulles International Airport in Virginia let passengers catch two sunsets – one as the plane took off in London and another after it landed near DC.

Ashley P. Taylor, writer for *Popular Mechanics*



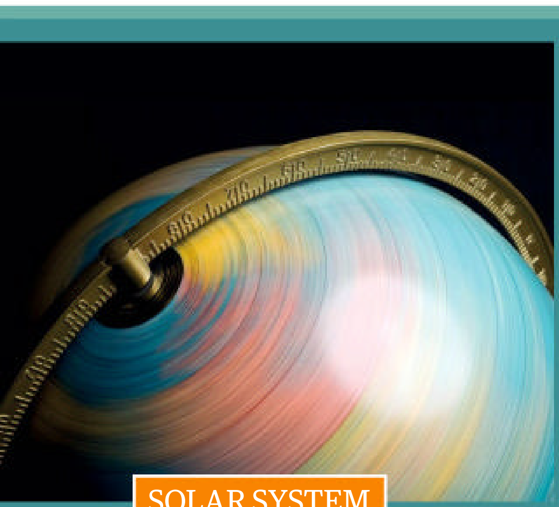
Below: Concorde planes would have been able to keep up with sunsets, even at the equator

"IF YOU WANTED TO FOLLOW THE SUNSET YOU WOULD NEED TO STAY IN THE SAME POSITION RELATIVE TO THE SUN AS THE EARTH TURNS UNDERNEATH YOU" ASHLEY TAYLOR

© Gerty

ASK Space

Our experts answer your questions



© Getty

SOLAR SYSTEM

What would happen if Earth began rotating in the opposite direction?

Prevailing winds would switch direction, with profound consequences on the climate - especially in the midlatitudes. Earth's rotation has a significant effect on weather patterns because it results in the Coriolis force. Wind flows from high pressure to low pressure, but the Coriolis force deflects this wind to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This is why wind flow around low and high-pressure systems circulates in opposing directions in each hemisphere. If Earth began rotating in the opposite direction, the Coriolis force would deflect the wind the other way around.

The jet stream, which helps develop and steer low pressure from the North Atlantic to northern Europe, would change direction. Northern Europe's prevailing winds would become easterly. The UK would have a more continental climate, similar to Newfoundland, which is at the same latitude. With less of an Atlantic influence, it would be drier and sunnier. Summers would be pleasant; winters would be brutal, with average temperatures below -10 degrees Celsius.

© Crown copyright

Aidan McGivern, Met Office meteorologist

Left: Earth's rotation affects global weather

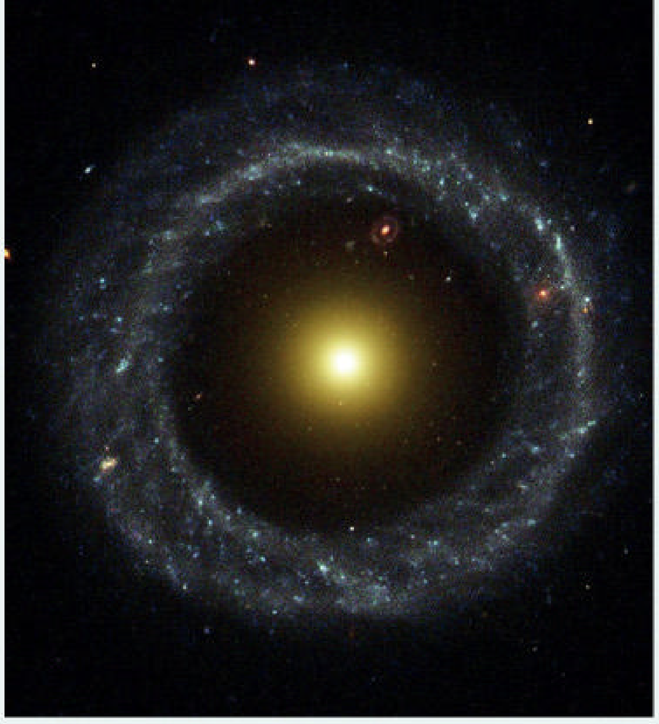
Right: Hoag's Object spans around 100,000 light years and lies about 600 million light years away from Earth

GALAXIES

What is Hoag's Object?

Hoag's Object is one of the most spectacular 'ring galaxies' in the night sky. Unlike normal spiral galaxies, gas and star formation are not distributed in spiral arms throughout its disc, but instead concentrated in a ring. Ring galaxies can be formed in several ways. If one galaxy collides head on with another, shock waves can propagate out through the galaxy disc - just like those seen when you drop a pebble into a pond. This can trigger star formation in a ring as the shock wave passes.

Alternatively, rings can be formed by a stellar bar, an elongated stellar component many galaxies have in their centres. As these rotate, they can create 'bar deserts' devoid of gas and rings where the expelled material congregates. Finally, rings can be formed as two galaxies fly by each other.



© NASA

Gas can be pulled out of the lower mass galaxy as it passes, which eventually settles into a ring. This fly-by scenario is currently the one preferred to explain Hoag's Object. The elliptical galaxy at the core of the system interacted with another galaxy billions of years ago, accreting the gas forming the beautiful ring we see today.

Dr Timothy Davis, senior lecturer, Cardiff University

SOLAR SYSTEM

Why do comets orbit the Sun in an elliptical path?

All objects orbiting the Sun travel on approximately elliptical paths because of the laws of gravitational motion. For example, Earth's orbit is elliptical, but not as elliptical as cometary orbits.

Many objects in the outer reaches of the Solar System - beyond Jupiter's orbit - are icy and small. Some, which travel on paths which are mildly elliptical, remain cold and water-rich. Others, which are on highly elliptical paths and pass close to the Sun, produce tails of gas and dust. These tails define comets. Comets must travel on highly elliptical orbits just to reach close to the Sun. But there is a twist. In 2019, a potentially comet-like object named Borisov from outside of our Solar System passed through and close to the Sun, and is now on its way out on a hyperbolic path.

This interloper never orbited the Sun on an elliptical path, but appears to be icy like typical comets. As a result, Borisov might force us to rethink our naming of and assumptions about comets.

Dr Dimitri Veras, associate professor and STFC Ernest Rutherford Fellow at the University of Warwick

Below: The laws of gravitational motion determine a comet's elliptical orbit

© Getty

Did you know?

Our Solar System resides in the Orion-Cygnus Arm of the Milky Way. Our galaxy has four major arms.

ASTRONOMY

How do we know the Milky Way is a spiral galaxy?

We don't know exactly how the Milky Way would look to an outside observer because we are within the galaxy itself. However, by mapping the location, distances and velocities of the stars, we can determine a lot about the Milky Way and its structure, including any spiral arms – regions with large amounts of dust and gas which can fuel the formation of new stars. We can then reconstruct what the Milky Way would look like to an outside observer.

Even without telescopes we are given clues about the Milky Way. Looking up into the night sky, you will see a thin ribbon of stars stretching across, implying that the galaxy is a thin, disc-like shape. With telescopes we can go much further by accurately mapping the positions and velocities of these stars. From this we see that stars are orbiting about the galactic centre in a similar way to the planets in our Solar System orbiting the Sun. Mapping the stars in this way, we can also identify the location of any spiral arms. In the case of the Milky Way, current data shows the presence of four main spiral arms.

Stephen Molyneux, European Southern Observatory

© ESO

Above: We can learn a lot about the Milky Way by mapping its stars

© ESO

WHAT'S IN THE SKY?

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> "THE MOON WILL PASS IN FRONT OF URANUS, CREATING A LUNAR OCCULTATION IN ARIES"

RED-LIGHT FRIENDLY

In order to preserve your night vision, you should read our observing guide under red light

29 JAN
The Moon and Mars make a close approach, passing within 2°24' of each other in Sagittarius

29 JAN
Conjunction between the Moon and Mars in Sagittarius

31 JAN
Open star cluster Messier 44 is well placed for observation in Cancer

6 FEB
Venus reaches its greatest brightness of -4.6 in the dawn sky

7 FEB
The Moon will pass in front of Uranus, creating a lunar occultation in Aries

Source: Wikipedia Commons ©Stuart Heggie

13 FEB
Conjunction between Venus and Mars in Sagittarius

16 FEB
Mercury reaches greatest elongation west in the dawn sky, shining at -0.0

16 FEB
Venus reaches its highest point in the dawn sky, dazzling at magnitude -4.4

JARGON BUSTER

CONJUNCTION

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

RIGHT ASCENSION (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

DECLINATION (DEC)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

MAGNITUDE

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

OPPOSITION

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

GREATEST ELONGATION

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

2 FEB

Comet 19P/Borrelly will make its close approach to the Sun, predicted to reach magnitude +9.0

7 FEB

The Moon and Uranus make a close approach, passing within 1°04' of each other in Aries

11 FEB

Mercury reaches its half phase in the dawn sky, shining brightly at magnitude 0.0

19 FEB

Bode's Galaxy (Messier 81) is well placed in Ursa Major

5 FEB

Asteroid 20 Massalia reaches opposition, glowing at magnitude +8.5 in Cancer

Source: Wikipedia Commons ©Astronomical Institute of the Charles University

©NASA, ESA and the Hubble Heritage Team

6 FEB

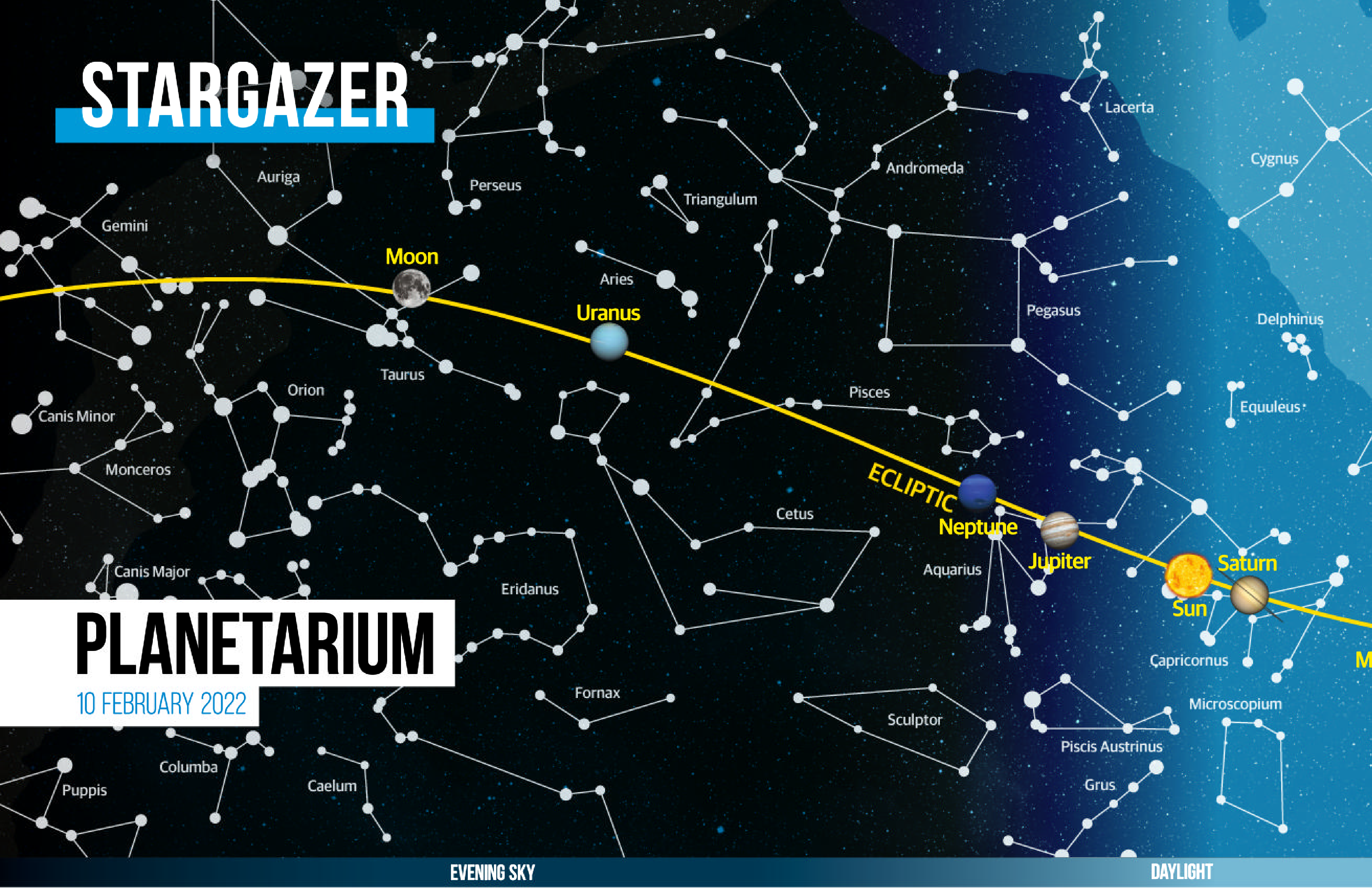
Mercury reaches its highest point in the sky, dazzling at magnitude -0.0

- 👁 Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

STARGAZER

PLANETARIUM

10 FEBRUARY 2022


Auriga
Perseus
Triangulum
Andromeda
Lacerta
Cygnus
Gemini
Moon
Aries
Uranus
Pegasus
Delphinus
Taurus
Orion
Canis Minor
Pisces
Equuleus
Monceros
ECLIPTIC
Neptune
Cetus
Jupiter
Saturn
Aquarius
Sun
Canis Major
Eridanus
Capricornus
Microscopium
Fornax
Sculptor
Piscis Austrinus
Columba
Puppis
Caelum
Grus
EVENING SKY
DAYLIGHT

MOON CALENDAR

* The Moon does not pass the meridian on 16 February

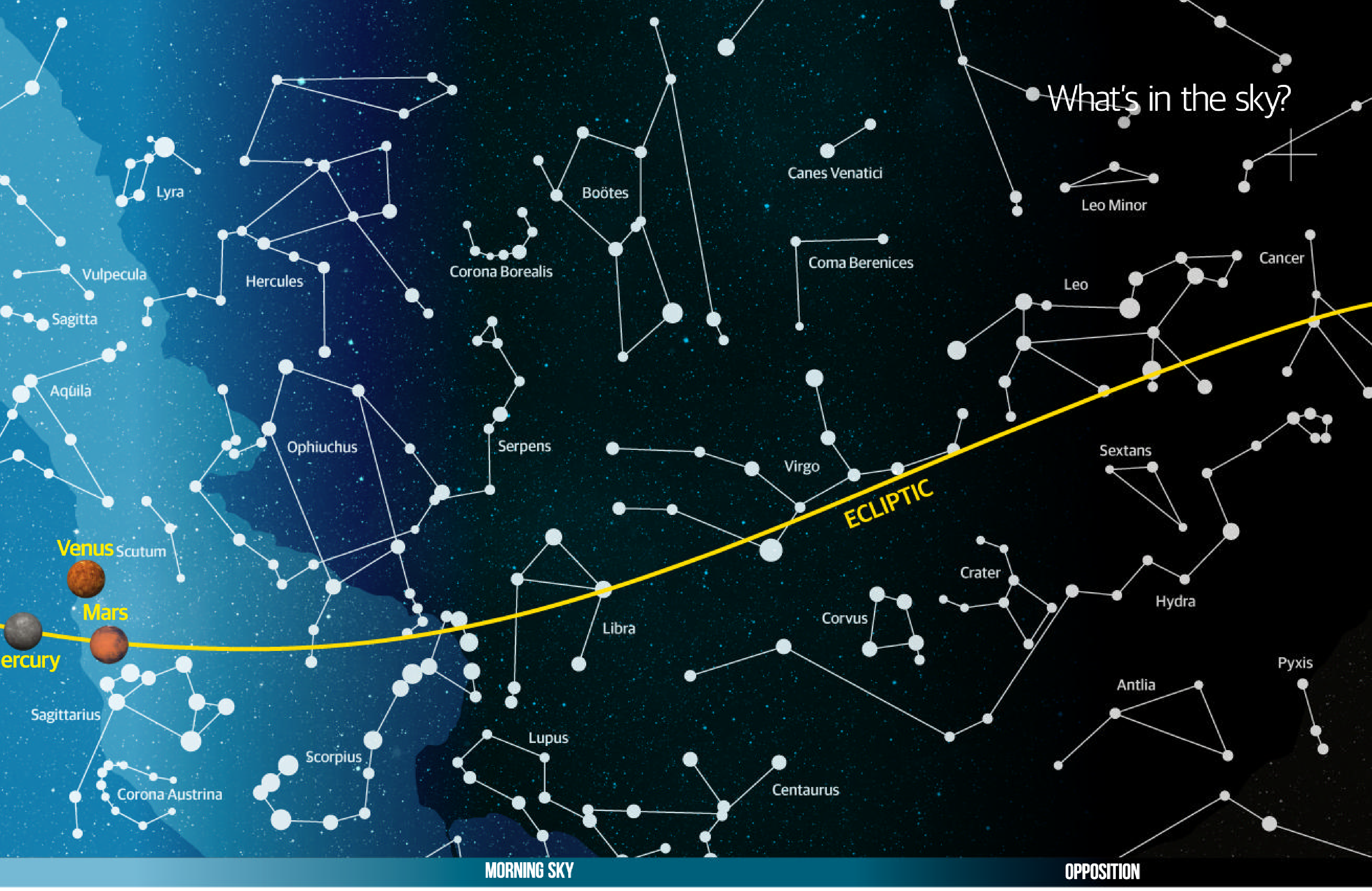
			27 JAN 30.9% ▲03:01 ▼11:38	28 JAN 20.3% ▲04:27 ▼12:12	29 JAN 11.4% ▲05:49 ▼13:01	30 JAN 4.7% ▲06:57 ▼14:08
31 JAN 1.0% ▲07:48 ▼15:29	1 FEB NM 0.3% ▲08:24 ▼16:57	2 FEB 2.6% ▲08:50 ▼18:24	3 FEB 7.5% ▲09:09 ▼19:47	4 FEB 14.4% ▲09:25 ▼21:06	5 FEB 22.8% ▲09:39 ▼22:22	6 FEB 32.1% ▲09:53 ▼23:36
7 FEB 41.9% ▲10:07 ▼--:--	8 FEB FQ 51.8% ▼00:48 ▲10:23	9 FEB 61.5% ▼02:00 ▲10:43	10 FEB 70.7% ▼03:10 ▲11:08	11 FEB 79.0% ▼04:17 ▲11:41	12 FEB 86.4% ▼05:17 ▲12:25	13 FEB 92.4% ▼06:07 ▲13:20
14 FEB 96.8% ▼06:48 ▲14:25	15 FEB 99.3% ▼07:19 ▲15:37	16 FEB FM --:--%* ▼07:42 ▲16:52	17 FEB 99.7% ▼08:01 ▲18:09	18 FEB 97.9% ▼08:17 ▲19:26	19 FEB 93.8% ▼08:32 ▲20:44	20 FEB 87.5% ▼08:46 ▲22:03
21 FEB 79.2% ▼09:01 ▲23:24	22 FEB 69.3% ▼09:18 ▲--:--	23 FEB TQ 58.2% ▲00:48 ▼09:40	24 FEB 46.5% ▲02:13 ▼10:10			

% Illumination
▲ Moonrise time
▼ Moonset time

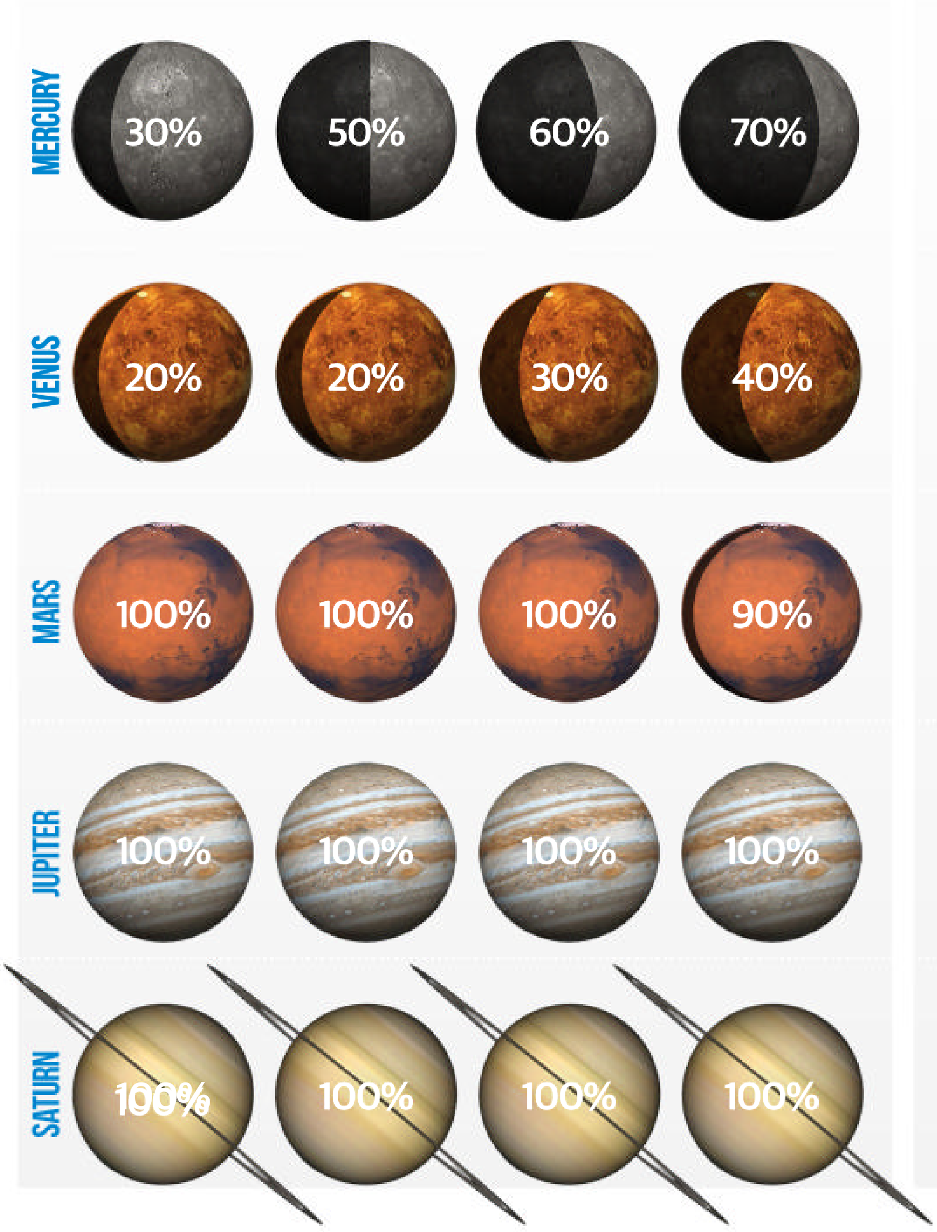
FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)

What's in the sky?


Canes Venatici
Leo Minor
Lyra
Boötes
Cancer
Vulpecula
Hercules
Corona Borealis
Coma Berenices
Leo
Sagitta
Aquila
Ophiuchus
Serpens
Virgo
Sextans
ECLIPTIC
Venus
Scutum
Crater
Mars
Hydra
Libra
Corvus
ercury
Pyxis
Antlia
Sagittarius
Lupus
Scorpius
Corona Austrina
Centaurus
MORNING SKY
OPPOSITION

ILLUMINATION PERCENTAGE



	3 FEB	10 FEB	17 FEB	24 FEB
MERCURY	30%	50%	60%	70%
VENUS	20%	20%	30%	40%
MARS	100%	100%	100%	90%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

PLANET POSITIONS

All rise and set times are given in GMT

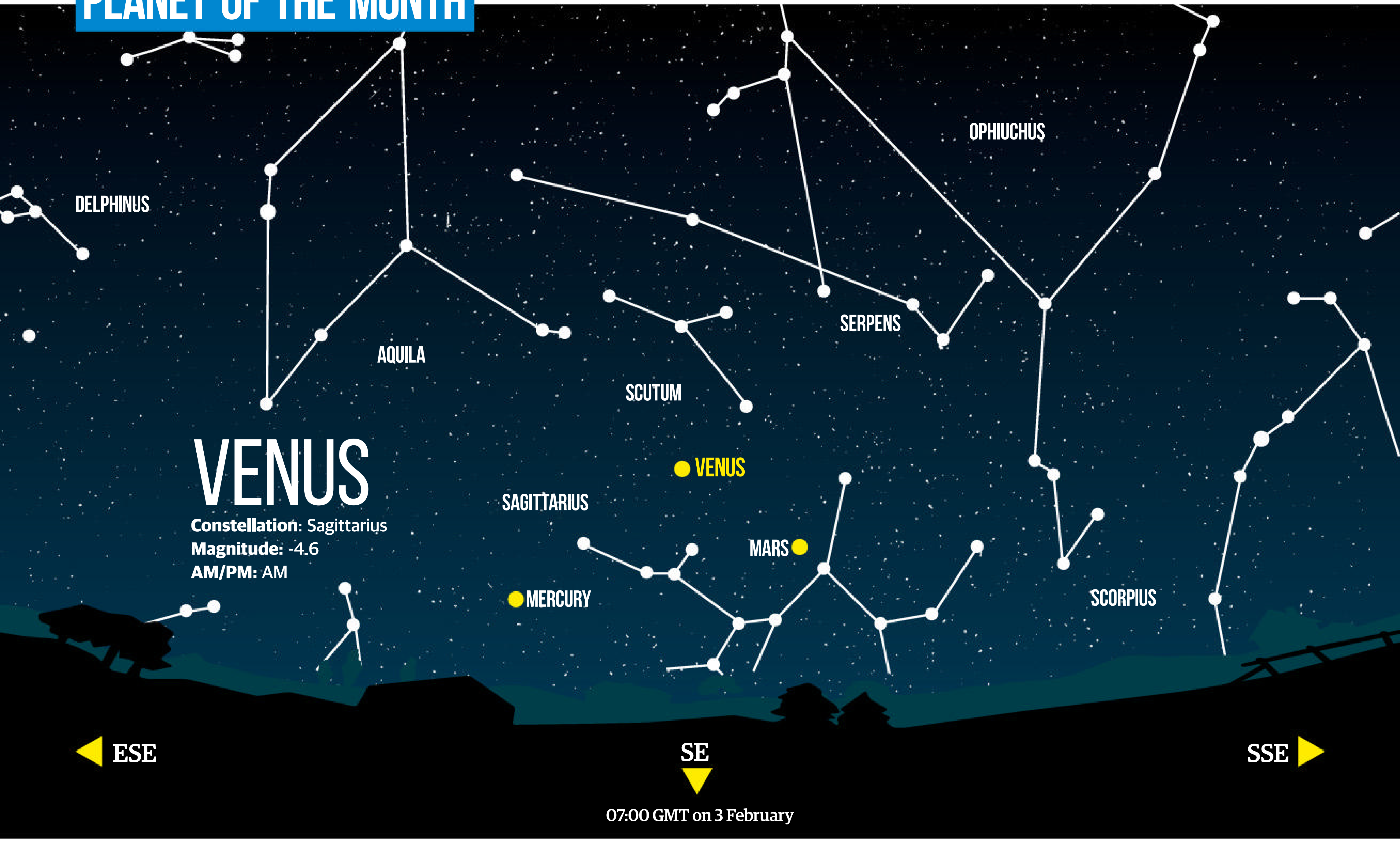
DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
27 JAN	20h 00m 14s	-16° 55' 30"	Sagittarius	+ 3.3	07:03	16:11
3 FEB	19h 42m 06s	-18° 27' 19"	Sagittarius	+0.7	06:24	15:14
10 FEB	19h 50m 29s	-19° 26' 23"	Sagittarius	+0.1	06:11	14:48
17 FEB	20h 15m 33s	-19° 31' 19"	Capricornus	0.0	06:09	14:46
24 FEB	20h 49m 31s	-18° 35' 03"	Capricornus	-0.1	06:11	15:00
27 JAN	18h 45m 02s	-16° 11' 16"	Sagittarius	-4.5	05:40	14:57
3 FEB	18h 46m 22s	-16° 20' 10"	Sagittarius	-4.6	05:16	14:31
10 FEB	18h 53m 30s	-16° 34' 56"	Sagittarius	-4.6	05:03	14:16
17 FEB	19h 10m 01s	-16° 53' 48"	Sagittarius	-4.6	04:50	13:59
24 FEB	19h 29m 34s	-17° 00' 33"	Sagittarius	-4.6	04:42	13:49
27 JAN	18h 06m 29s	-23° 51' 30"	Sagittarius	+ 1.4	05:52	13:31
3 FEB	18h 28m 48s	-23° 47' 11"	Sagittarius	+ 1.4	05:48	13:28
10 FEB	18h 51m 10s	-23° 31' 03"	Sagittarius	+ 1.4	05:39	13:23
17 FEB	19h 13m 31s	-23° 03' 08"	Sagittarius	+ 1.3	05:32	13:23
24 FEB	19h 35m 49s	-22° 23' 40"	Sagittarius	+ 1.3	05:20	13:20
27 JAN	22h 31m 41s	-10° 18' 10"	Aquarius	-2.1	08:57	19:19
3 FEB	22h 37m 44s	-09° 42' 21"	Aquarius	-2.0	08:30	18:58
10 FEB	22h 43m 53s	-09° 05' 31"	Aquarius	-2.0	08:07	18:42
17 FEB	22h 50m 07s	-08° 27' 51"	Aquarius	-2.0	07:40	18:21
24 FEB	22h 56m 24s	-07° 49' 33"	Aquarius	-2.0	07:17	18:05
27 JAN	21h 09m 12s	-17° 15' 41"	Capricornus	+0.7	08:11	17:15
3 FEB	21h 12m 34s	-17° 01' 19"	Capricornus	+0.7	07:48	16:55
10 FEB	21h 15m 55s	-16° 46' 46"	Capricornus	+0.7	07:21	16:31
17 FEB	21h 19m 15s	-16° 32' 10"	Capricornus	+0.7	06:55	16:07
24 FEB	21h 22m 32s	-16° 17' 39"	Capricornus	+0.8	06:28	15:43

STARGAZER

THIS MONTH'S PLANETS

Observe before dawn and you'll be able to catch dazzling Venus, Mercury and Mars in all their glory

PLANET OF THE MONTH



07:00 GMT on 3 February

VENUS

Constellation: Sagittarius
Magnitude: -4.6
AM/PM: AM

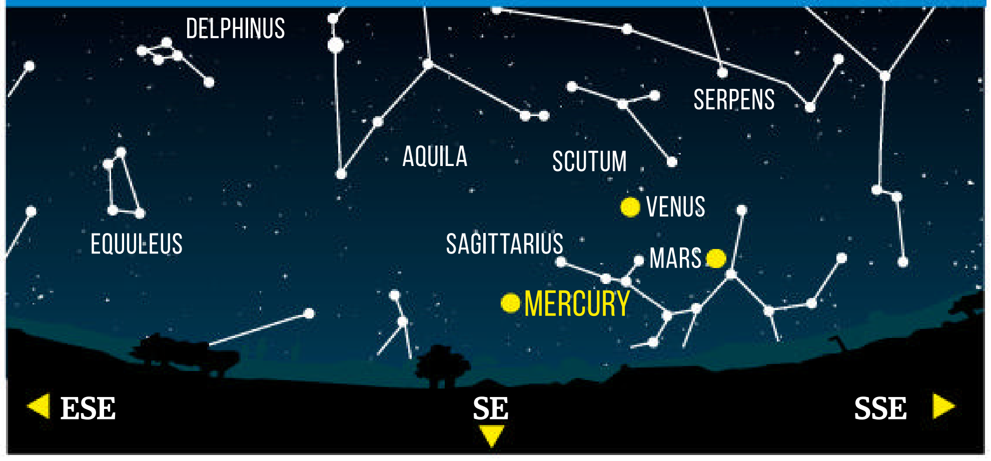
Venus is our planet of the month, not just because it will be so strikingly bright – and therefore easy to see – in the sky before dawn, but because it will have lots of company in the sky during our observing period. Having played 'second fiddle' to Mars for many years, Venus is now well and truly in the scientific spotlight. Various space agencies and private companies are planning on sending missions there to study and map its surface and even look for signs of life in its atmosphere.

We already know, thanks to previous missions, that Venus is roughly the same size as Earth, so much so that it is often called 'Earth's twin', but that is where the family similarity ends. Venus is a hellish planet, and walking on its rocky surface would be like walking in a furnace; the same thick, curdled atmosphere of poisonous carbon dioxide gas which makes Venus shine so brightly in our sky, reflecting the Sun's light like a mirror, traps the Sun's heat so efficiently that the planet's surface temperature is close to 400 degrees Celsius (752 degrees Fahrenheit). Its thickness also gives Venus a surface pressure so lethally high anyone landing on it would need a special pressure suit, like a deep-sea diver, to stay alive.

At the end of January Venus will be a brilliant 'morning star', blazing in the southeast before dawn, brighter by far than anything else in that part of the sky and rising almost two hours before the Sun floods the sky with light.

By 3 February Venus will form a predawn triangle with two other worlds, both much fainter, but easy to spot because of their proximity to dazzling Venus. To Venus' lower left you'll see Mercury, looking like a fainter, more copper-hued star, and to Venus' lower right you'll spot orange-coloured Mars. If you have a DSLR camera – or a good camera on your phone – this planetary pyramid will be a great target if you're up early enough to see it. By 10 February Venus will be at its best – a dazzling silvery lantern dominating the sky before dawn, close to Mars and rising more than two hours before the Sun – but after that it will start to move back towards the Sun and its visibility will decrease.

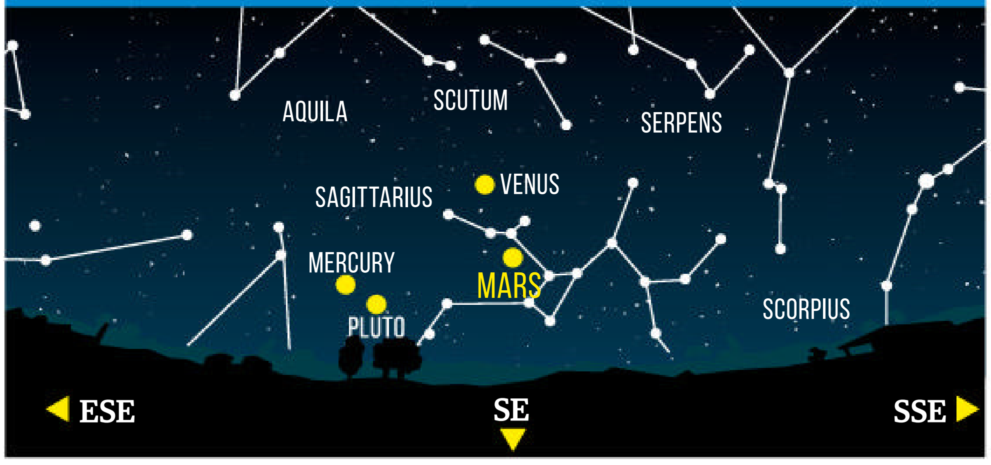
MERCURY 07:00 GMT on 3 February


DELPHINUS
SERPENS
AQUILA
SCUTUM
VENUS
EQUULEUS
SAGITTARIUS
MARS
MERCURY
ESE
SE
SSE

Constellation: Sagittarius **Magnitude:** +0.8 **AM/PM:** AM

At the start of our observing period Mercury, closest planet to the Sun, will be a faint 'morning star' shining low in the southeast before sunrise, to the lower left of much brighter Venus. As the days pass it will brighten, and its visibility will improve. It will be furthest from the Sun on the morning of 3 February, when it will be rising around an hour before the Sun.

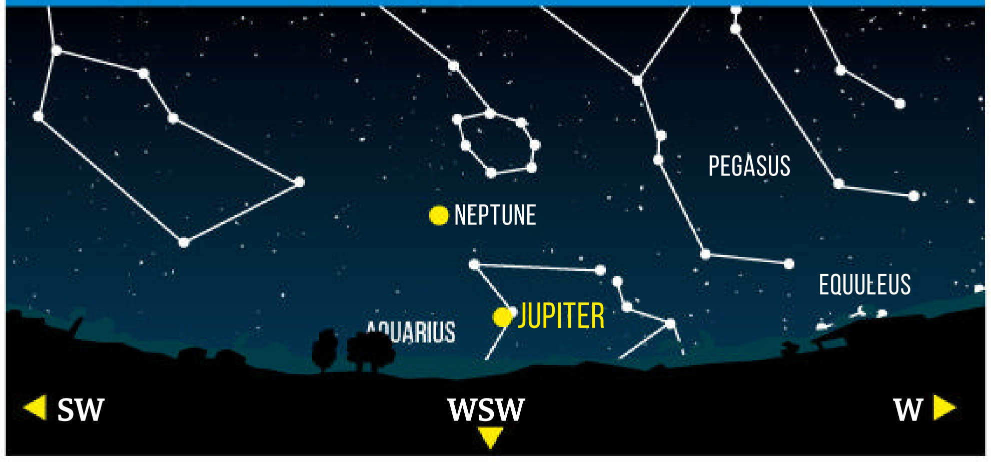
MARS 07:00 GMT on 14 February


AQUILA
SCUTUM
SERPENS
SAGITTARIUS
VENUS
MERCURY
MARS
PLUTO
SCORPIUS
ESE
SE
SSE

Constellation: Sagittarius **Magnitude:** +1.4 **AM/PM:** AM

Mars will be visible in the morning sky, looking like an orange-hued star shining to the lower right of Venus, rising around 90 minutes before the Sun. At the start of February the Red Planet will be shining at a respectable +1.4, but won't be as strikingly obvious to the naked eye as that figure suggests because it will be low in the sky and in the predawn twilight.

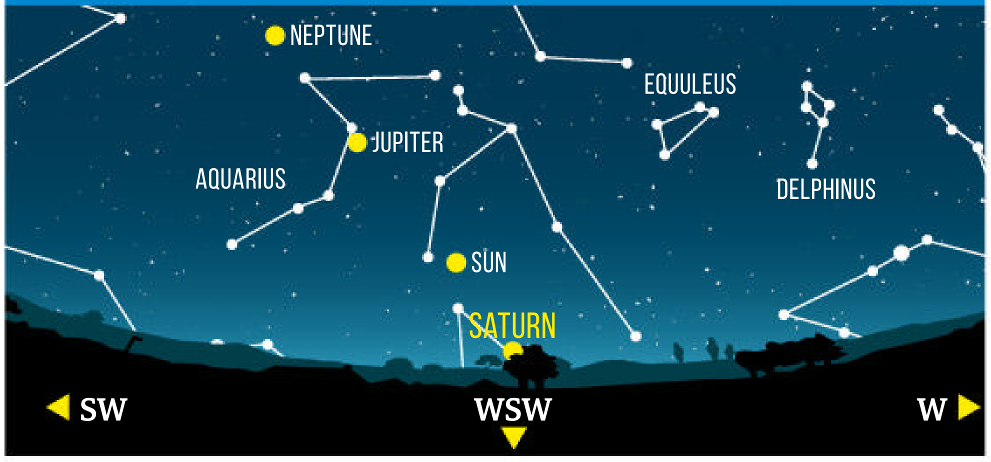
JUPITER 17:30 GMT on 19 February


PEGASUS
NEPTUNE
EQUULEUS
AQUARIUS
JUPITER
SW
WSW
W

Constellation: Aquarius **Magnitude:** -2.9 **AM/PM:** PM

Jupiter, the largest planet in our Solar System, will be a naked eye planet during the month ahead. It will be visible in the evening sky all through February, looking like a bright, blue-white star low in the southwest straight after sunset and not setting until two hours after the Sun. As the month progresses Jupiter's visibility will decrease as it moves towards the Sun.

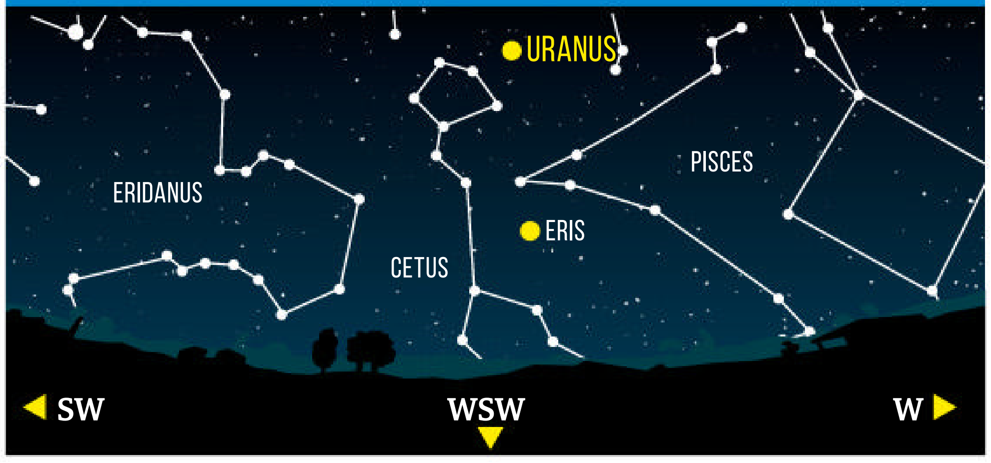
SATURN 16:00 GMT on 15 February


NEPTUNE
EQUULEUS
JUPITER
AQUARIUS
DELPHINUS
SUN
SATURN
SW
WSW
W

Constellation: Capricornus **Magnitude:** +0.7 **AM/PM:** PM

At the start of our observing period Saturn will be so close to the Sun in the sky it will be difficult to see. Soon after it will move too close to the Sun to be seen at all, and we'll then lose sight of it for a while as it passes behind the Sun. In mid-February Saturn will move into the morning sky, but it will remain extremely hard to see for a while until it has cleared the Sun's glare.

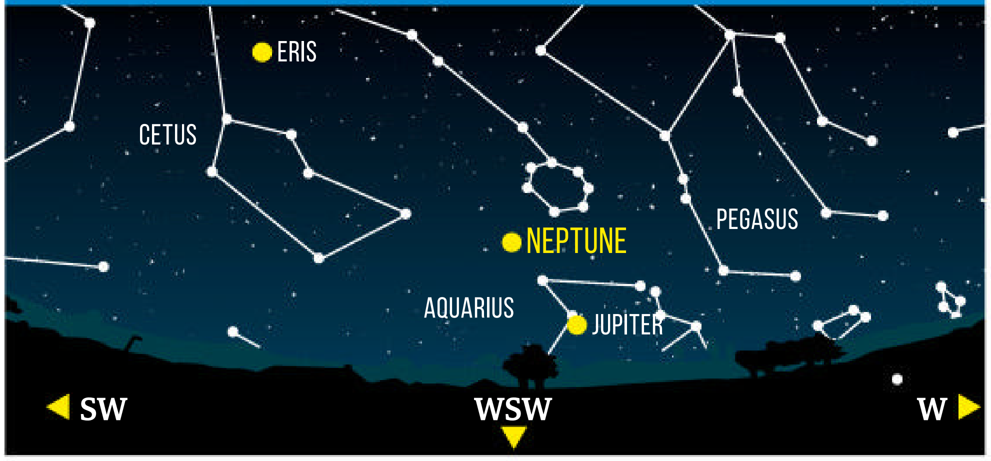
URANUS 20:00 GMT on 15 February


URANUS
PISCES
ERIDANUS
ERIS
CETUS
SW
WSW
W

Constellation: Aries **Magnitude:** +5.7 **AM/PM:** PM

During our observing period Uranus will be visible through the night and into the early hours. As the Sun sets it will already be high in the east, and it will slowly arc eastwards through the night, reaching its highest in the south around midnight. Shining at magnitude +5.7, Uranus will technically be visible to the naked eye, but you'll need to know where to find it.

NEPTUNE 18:00 GMT on 17 February


ERIS
CETUS
PEGASUS
NEPTUNE
AQUARIUS
JUPITER
SW
WSW
W

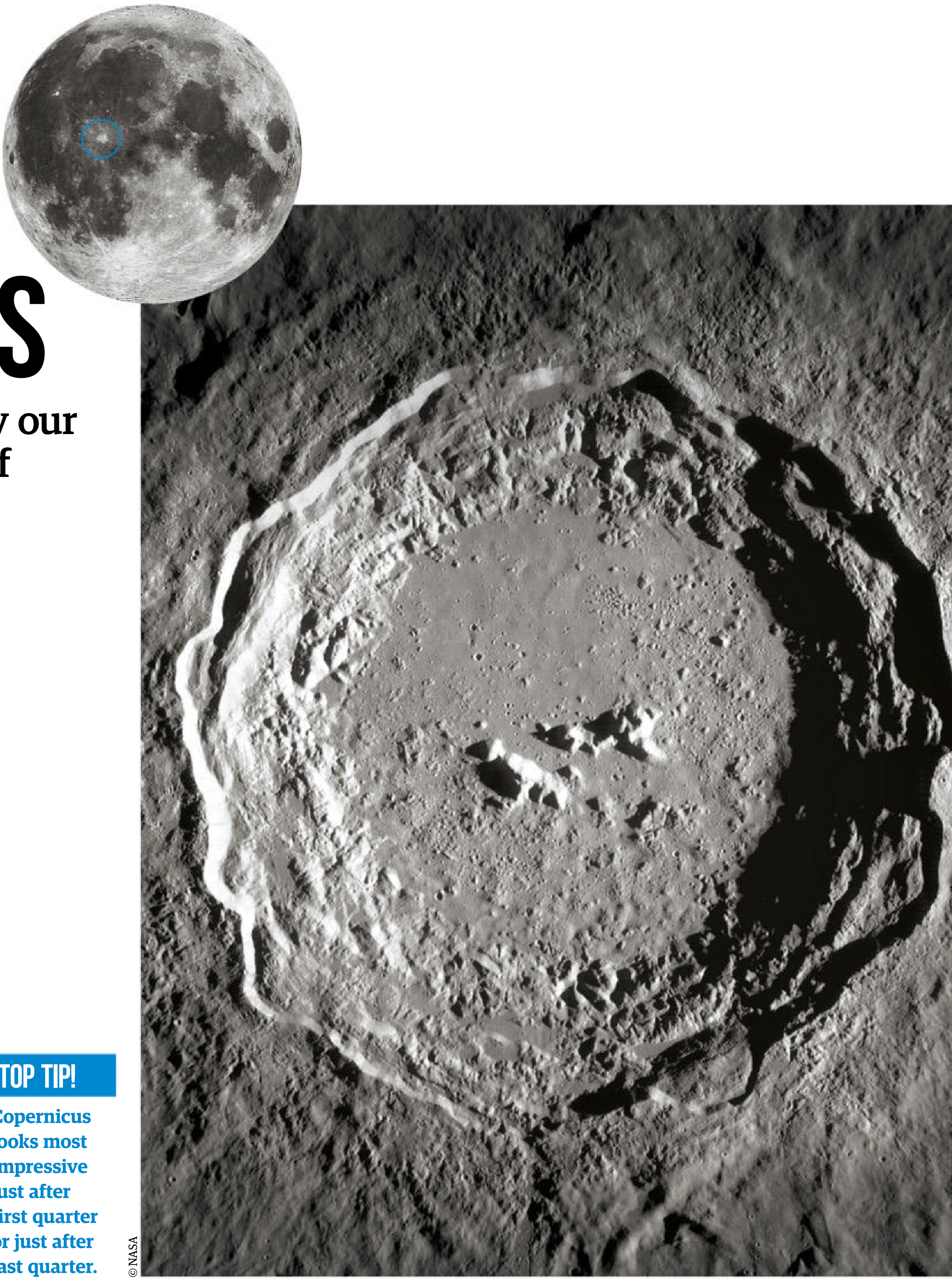
Constellation: Aquarius **Magnitude:** +8.0 **AM/PM:** PM

Neptune will be an evening object this month, visible after sunset in the southwest to the upper left of Jupiter. Because it's so far from the Sun, the distant planet is much too faint to be visible to the naked eye, so you'll need binoculars or a telescope. By the end of our observing period Neptune will be lost in the twilight, setting just over an hour after the Sun.

MOON TOUR

COPERNICUS

Early 2022 allows us to pay our respects to 'the Monarch of the Moon'



© NASA

If you've ever seen a documentary about the Moon, you'll have seen a scientist enthusiastically hurling a stone into a tray full of flour to demonstrate how impact craters are formed. Of all the hundreds of thousands of craters on the Moon, one looks exactly like the feature these dramatic demonstrations produce: a deep, sharp-edged pit, like a skull's eye socket, surrounded by rays of debris.

Copernicus looks exactly like a lunar crater should: a great hole in the Moon with a dark, shadowed floor; a high-reaching rim and lots of bright rays of dust and pulverised rock splashing away from it. Its nickname, the Monarch of the Moon, is entirely justified – no other crater comes close to it for sheer 'wow' factor when seen through a telescope's eyepiece. That's why Moon observers go back to it again and again and again, staring down into it every chance they get.

Copernicus is young in lunar terms. It was formed between 800 million and 1 billion years ago when the most advanced forms of life on Earth were essentially clumps of scum floating about in the oceans. One day the Moon was struck by a large asteroid, and the enormous explosion caused by the impact blasted a huge hole out of the area of the Moon we now know as Oceanus Procellarum, or the Ocean of Storms.

TOP TIP!

Copernicus looks most impressive just after first quarter or just after last quarter.

The gaping pit left behind was almost four kilometres (2.5 miles) deep and more than 93 kilometres (58 miles) wide. But the impact didn't just blast out a hole; it sent enormous amounts of debris spraying out across the lunar landscape. Some of it fell back down to the Moon, leaving bright rays of ejecta on the landscape. The longest of these debris rays stretches for over 800 kilometres (50 miles) and can even be seen with the naked eye when the Moon is full, looking like white chalk lines drawn on the Moon's darker face.

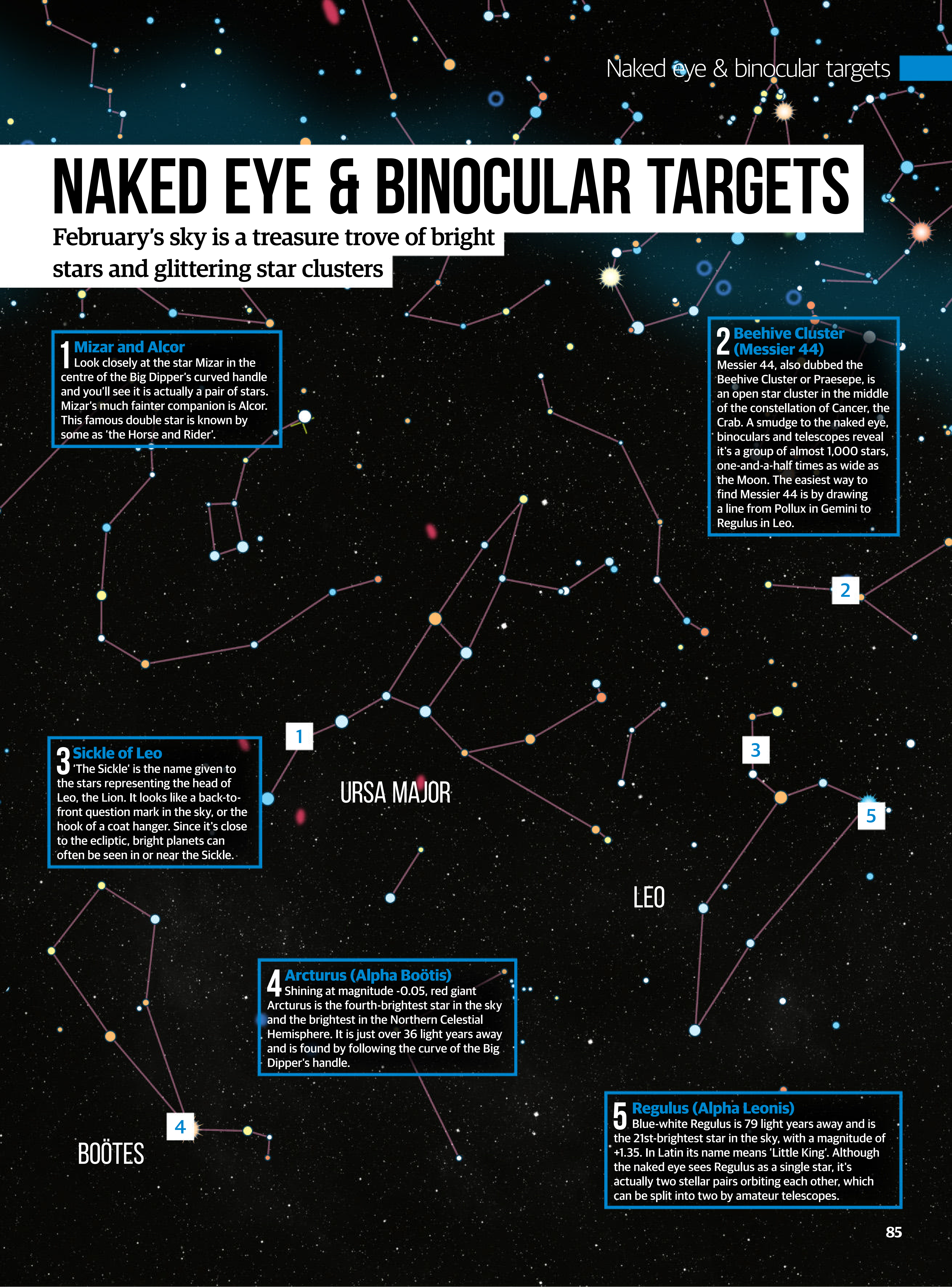
Seen through a telescope – or from an orbiting probe – Copernicus is roughly hexagonal in shape. Its walls are steep and terraced on all sides, giving the strong impression of a flight of stairs descending to its floor. High magnification shows where a wide shelf of rock has dropped down on the western side and also hints at landslides in several places. The northern part of the crater's floor is quite flat, but the southern half is hummocky and hilly, pocked here and there with many smaller, much younger craterlets. In the centre of the crater a trio of mountains protrude from the lava plain; the tallest one, close to the western wall, has a peak which rises above the crater's floor.

In November 1969 the Apollo 12 Lunar Module Intrepid set down at a landing site around 350 kilometres (217 miles) south of the huge crater. So precise was Intrepid's landing that its crew, Pete Conrad and Alan Bean, were able to walk to the Surveyor 3 probe. After carefully removing pieces of the probe to be studied back on Earth, they collected samples of rock, some of which might have showered from the sky after the formation of Copernicus almost a billion years earlier.

So how and when can you see this celebrity crater this month? At the start of our observing period Copernicus is hidden from view, deep in lunar night. You'll have to wait until the evening of 11 February for your first sighting of it as it emerges from the darkness with the approach of the terminator, the line between night and day. As lunar dawn breaks over Copernicus' eastern horizon it will come fully into view the next evening, the 12th, and from then until the 27th will be available for your attention with binoculars or a telescope. When the Moon is full on 16 February the crater's system of rays will appear at their most dramatic and obvious. By the 26th Copernicus will be hard to see as the terminator sweeps towards it, and it will vanish from our view on the 27th, swallowed up by the bitter lunar night once more when the Moon will be a waning crescent glowing in the east before dawn.

NAKED EYE & BINOCULAR TARGETS

February's sky is a treasure trove of bright stars and glittering star clusters



1 Mizar and Alcor

Look closely at the star Mizar in the centre of the Big Dipper's curved handle and you'll see it's actually a pair of stars. Mizar's much fainter companion is Alcor. This famous double star is known by some as 'the Horse and Rider'.

2 Beehive Cluster (Messier 44)

Messier 44, also dubbed the Beehive Cluster or Praesepe, is an open star cluster in the middle of the constellation of Cancer, the Crab. A smudge to the naked eye, binoculars and telescopes reveal it's a group of almost 1,000 stars, one-and-a-half times as wide as the Moon. The easiest way to find Messier 44 is by drawing a line from Pollux in Gemini to Regulus in Leo.

3 Sickle of Leo

'The Sickle' is the name given to the stars representing the head of Leo, the Lion. It looks like a back-to-front question mark in the sky, or the hook of a coat hanger. Since it's close to the ecliptic, bright planets can often be seen in or near the Sickle.

4 Arcturus (Alpha Boötis)

Shining at magnitude -0.05, red giant Arcturus is the fourth-brightest star in the sky and the brightest in the Northern Celestial Hemisphere. It is just over 36 light years away and is found by following the curve of the Big Dipper's handle.

5 Regulus (Alpha Leonis)

Blue-white Regulus is 79 light years away and is the 21st-brightest star in the sky, with a magnitude of +1.35. In Latin its name means 'Little King'. Although the naked eye sees Regulus as a single star, it's actually two stellar pairs orbiting each other, which can be split into two by amateur telescopes.

The Bubble Nebula (NGC 7635)

© NASA, ESA, Hubble Heritage Team

DEEP SKY CHALLENGE

THE KING'S JEWELS

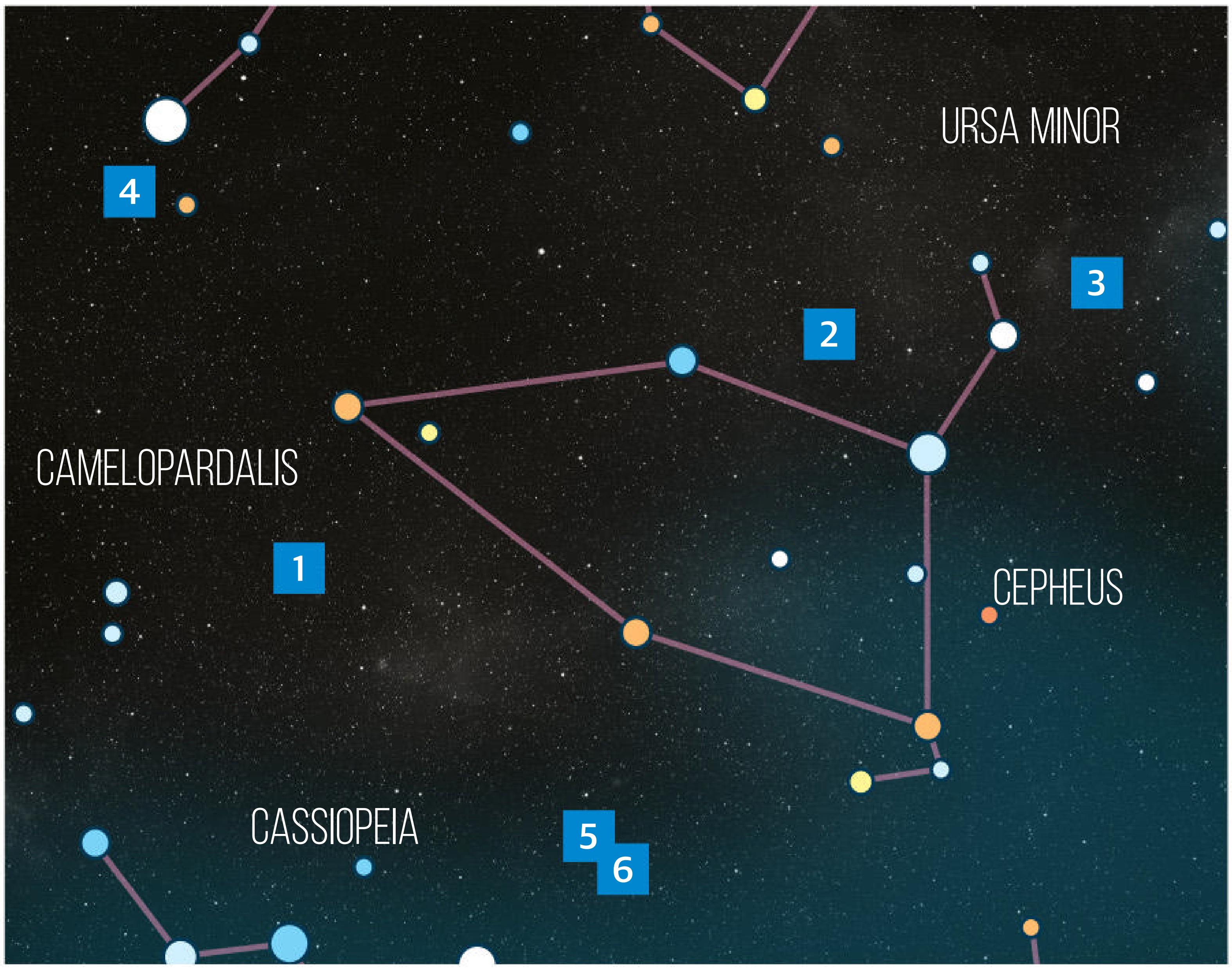
One of the least famous constellations offers keen-eyed observers some fascinating and beautiful sights

It's an unspoken truth that while some constellations are gorgeous and are blessed with spectacular telescopic treats, others can be just a little boring. With no bright stars, they are dull to the naked eye, and they have no big, bright deep-sky objects that cry out to admired through a low-power eyepiece. One such constellation is Cepheus, the King. To the naked eye its faint stars make the shape of a child's crude drawing of a house, and that's it. However, if you swing a medium or large-aperture telescope towards it, you'll be rewarded with views of some genuinely fascinating and attractive objects.

The spectacular spiral galaxy NGC 6946, known as the Fireworks Galaxy - actually in Cygnus but right on the border with Cepheus - is a popular photographic target for astrophotographers, and seeing it through a large telescope will show you why. This March, as the galaxies of Virgo call out to you from the east and the whirls and swirls of the Orion Nebula whisper from the west, put your hands over your ears, tilt your telescope up and take a tour of Cepheus and the sky around it instead. You'll be glad you did.

Iris Nebula (NGC 7023)

Source: Wikipedia Commons © Hewholooks



1 **Bow Tie Nebula (NGC 40)**
At magnitude +10.6, this dim planetary nebula needs an eight-inch or larger telescope to show its subtle oval shape. Its bright central star is more obvious.

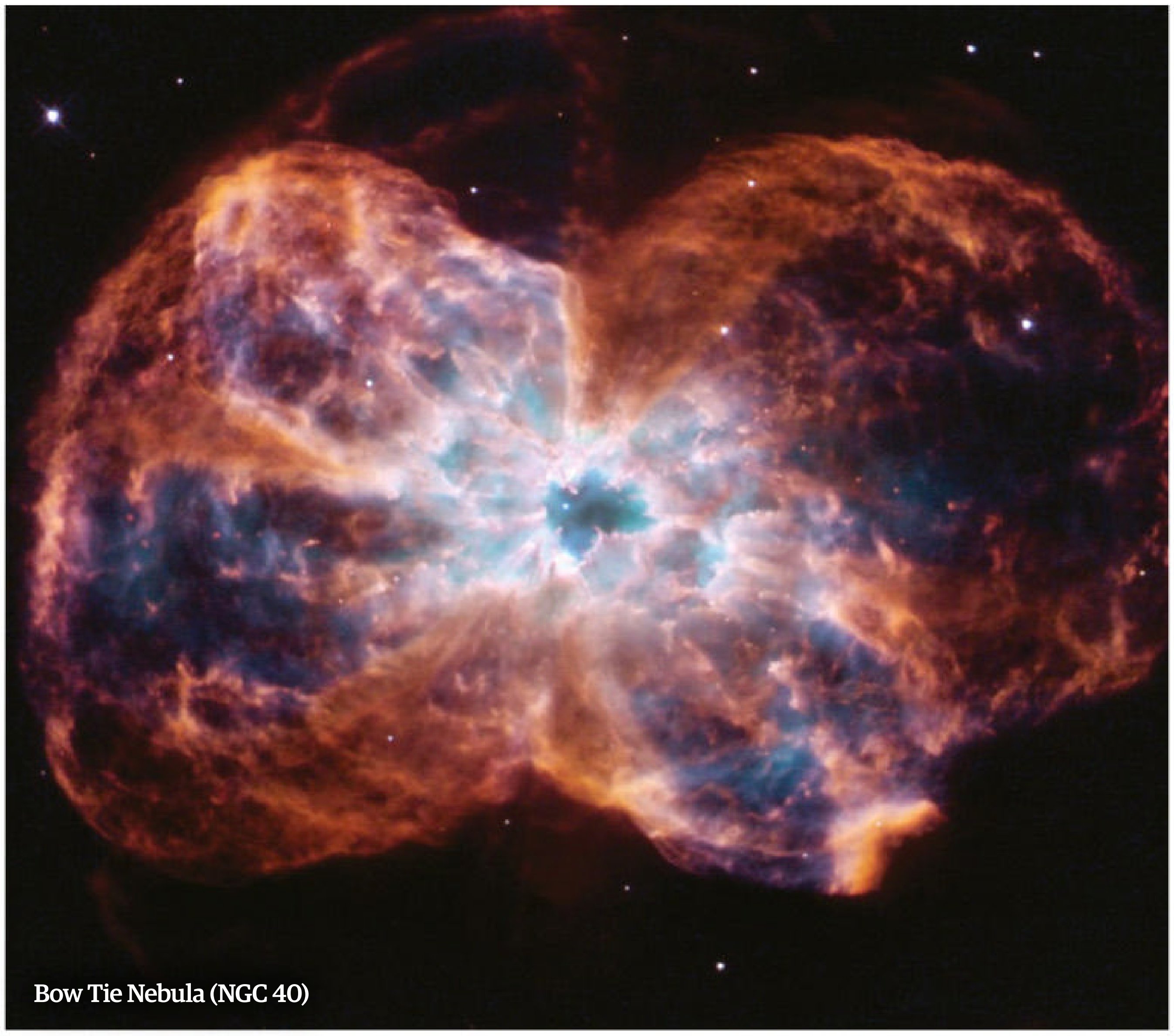
2 **Iris Nebula (NGC 7023)**
Despite being seventh magnitude, you'll need a large telescope to see this nebula due to its low surface brightness. Averted vision and high magnification will help highlight its dark dust lanes.

3 **Fireworks Galaxy (NGC 6946)**
This ninth-magnitude spiral galaxy is 10 million light years away. Oriented face on to us, under a dark sky a large telescope will reveal its beautifully curved spiral arms and mottled detail within them.

4 **NGC 188**
Very close to Polaris, this open cluster is 9 billion years old, one of the oldest known. It is an eighth-magnitude dusting of faint stars best seen through a large telescope.

5 **Bubble Nebula (NGC 7635)**
You'll only see the ghostly glowing shell of this very faint 12th-magnitude nebula in Cassiopeia through a large telescope under a very dark sky. A 14-inch telescope will show subtle details.

6 **Messier 52**
Just over Cepheus' border in Cassiopeia, this seventh-magnitude open cluster can be seen as a smudge through small telescopes, but larger instruments will resolve it into 200 or so faint stars.


Bow Tie Nebula (NGC 40)

© NASA/ESA

"TO THE NAKED EYE ITS FAINT STARS MAKE THE SHAPE OF A CHILD'S CRUDE DRAWING OF A HOUSE"

THE NORTHERN HEMISPHERE

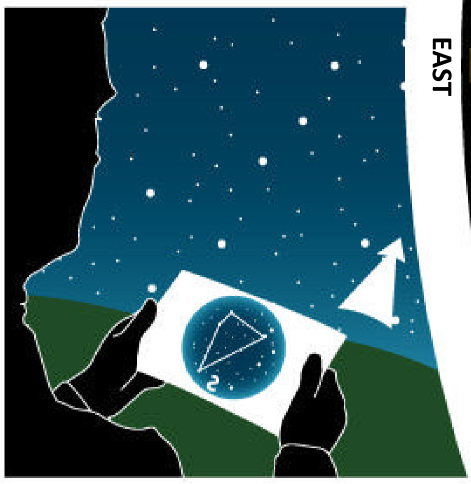
Plenty of objects are available to observers using the unaided eye, binoculars or a telescope

Throughout February and into the early days of March, observers using the unaided eye, binoculars or a telescope will be treated to a variety of targets. The Orion Nebula (Messier 42), which glows at a magnitude of +4.0 in the constellation of Orion, the Hunter, makes an excellent target for those using a pair of binoculars or a telescope, while the Andromeda Galaxy (Messier 31) is just about visible to the naked eye from areas untouched by light pollution and through telescopes and binoculars from urban regions. For those keen to observe in the early hours of the evening, the circumpolar galaxies of Ursa Major, including the Pinwheel Galaxy (Messier 101), are choice objects for deep-sky enthusiasts.

USING THE SKY CHART

This chart is for use at 22:00 mid-month and is set for 52° latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.



MAGNITUDES

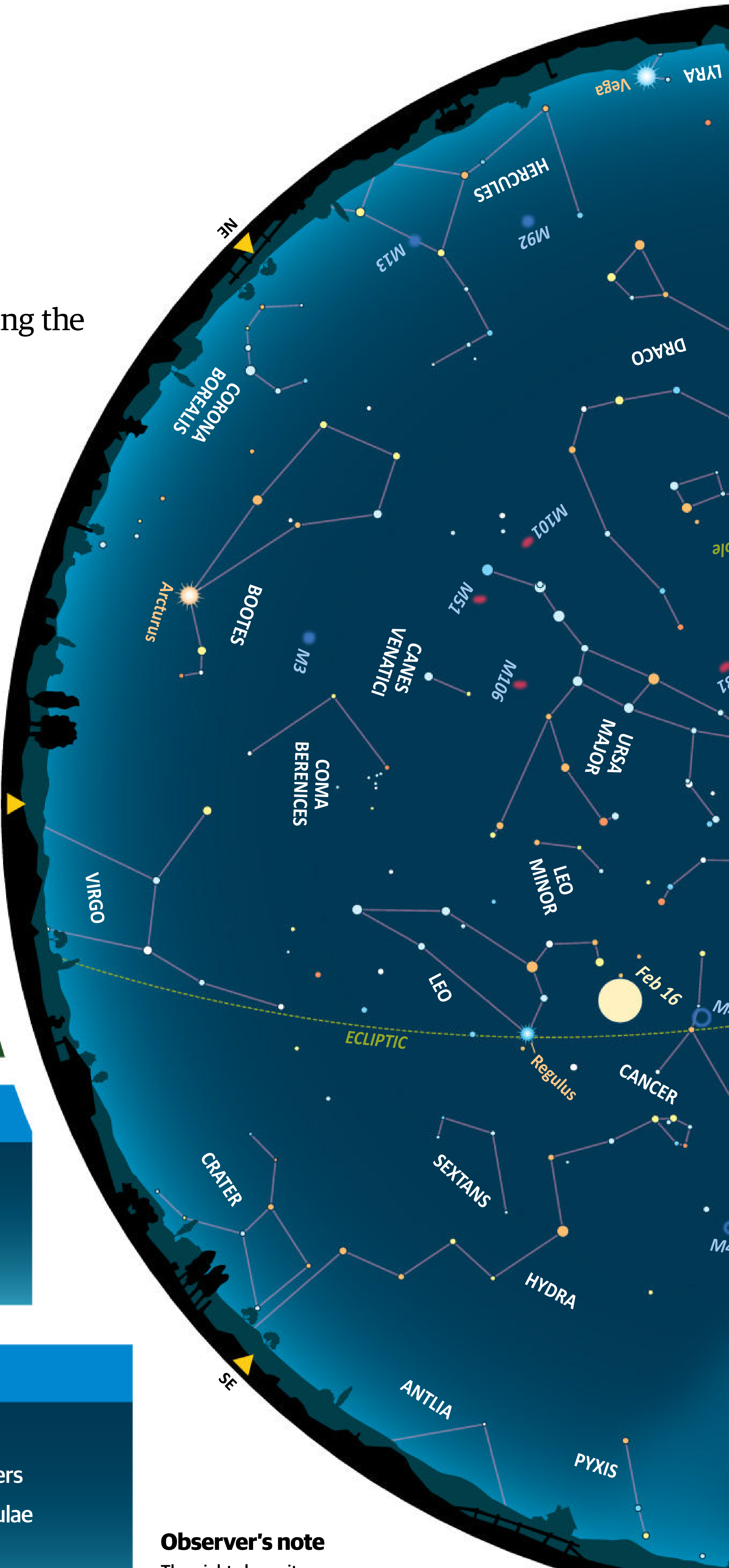
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

SPECTRAL TYPES

- O-B
- A
- F
- G
- K
- M

DEEP-SKY OBJECTS

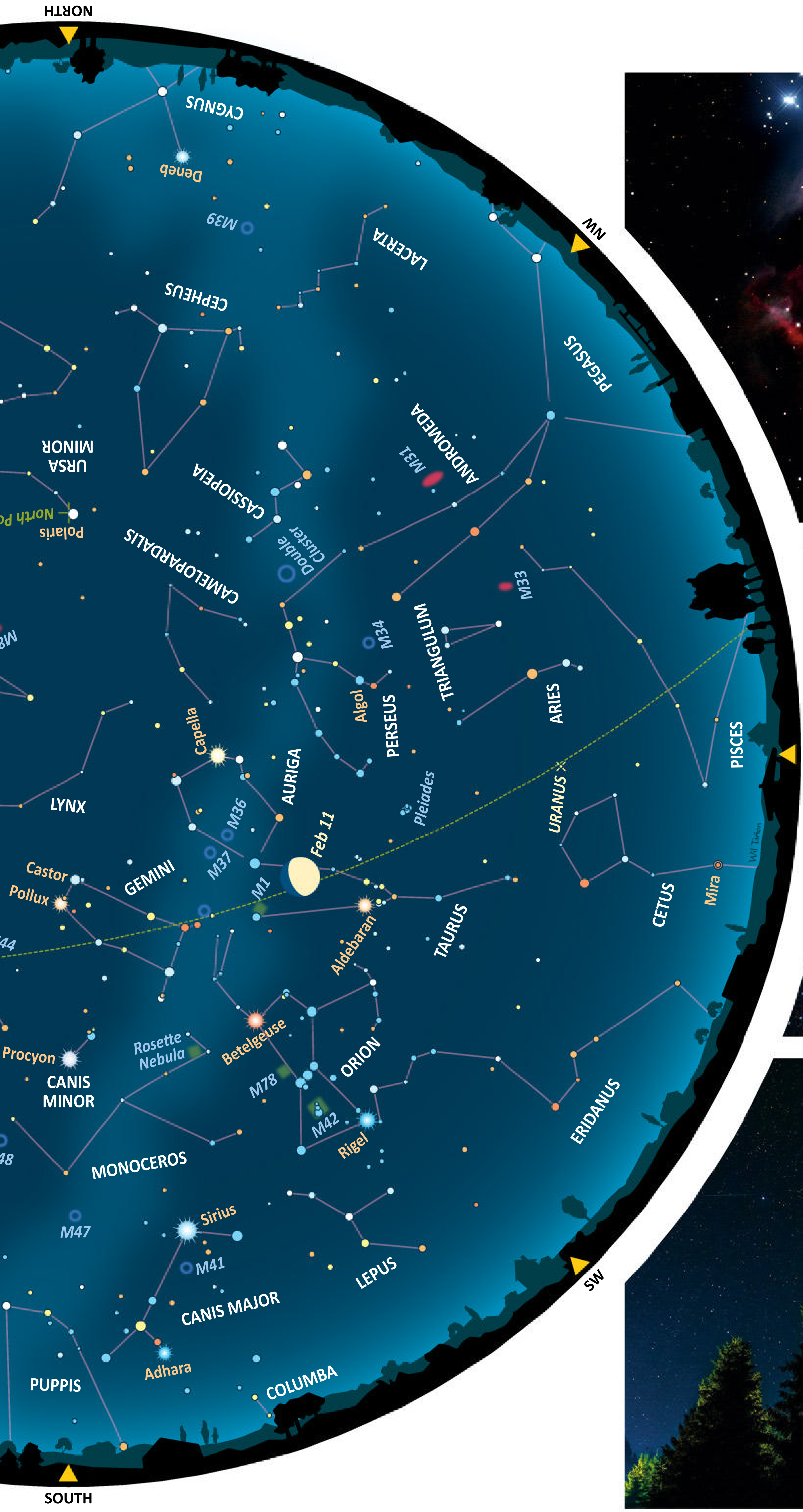
- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



LYRA
Vega
HERCULES
M92
M13
NE
DRACO
CORONA BOREALIS
M101
Arcturus
BOOTES
M51
CANES VENATICI
M3
M106
URSA MAJOR
COMA BERENICES
EAST
VIRGO
LEO MINOR
LEO
Feb 16
ECLIPTIC
Regulus
CANCER
CRATER
SEXTANS
HYDRA
SE
ANTLIA
PYXIS

Observer's note

The night sky as it appears on 17 February 2022 at approximately 22:00 (GMT)

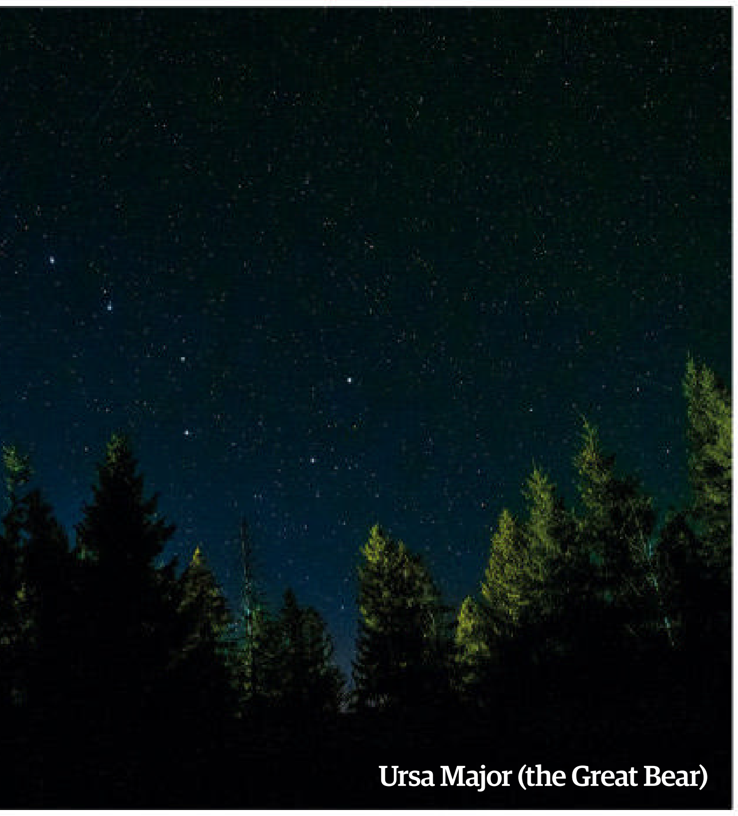

NORTH
CYGNUS
Deneb
M39
LACERTA
NW
CEPHEUS
PEGASUS
URSA MINOR
North Po
Polaris
ANDROMEDA
M31
CASSIOPEIA
Double Cluster
CAMELOPARDALIS
M33
M34
TRIANGULUM
Algol
PERSEUS
ARIES
Capella
AURIGA
PISCES
WEST
LYNX
M36
Feb 11
Pleiades
URANUS
M37
Castor
Pollux
GEMINI
M1
TAURUS
CETUS
Mira
Wil Tirion
44
Aldebaran
Procyon
Rosette Nebula
Betelgeuse
CANIS MINOR
M78
ORION
ERIDANUS
M42
Rigel
48
MONOCEROS
M47
Sirius
M41
LEPUS
SW
CANIS MAJOR
PUPPIS
Adhara
COLUMBA
SOUTH

Orion Nebula (Messier 42)

© Getty

Andromeda Galaxy (Messier 31)

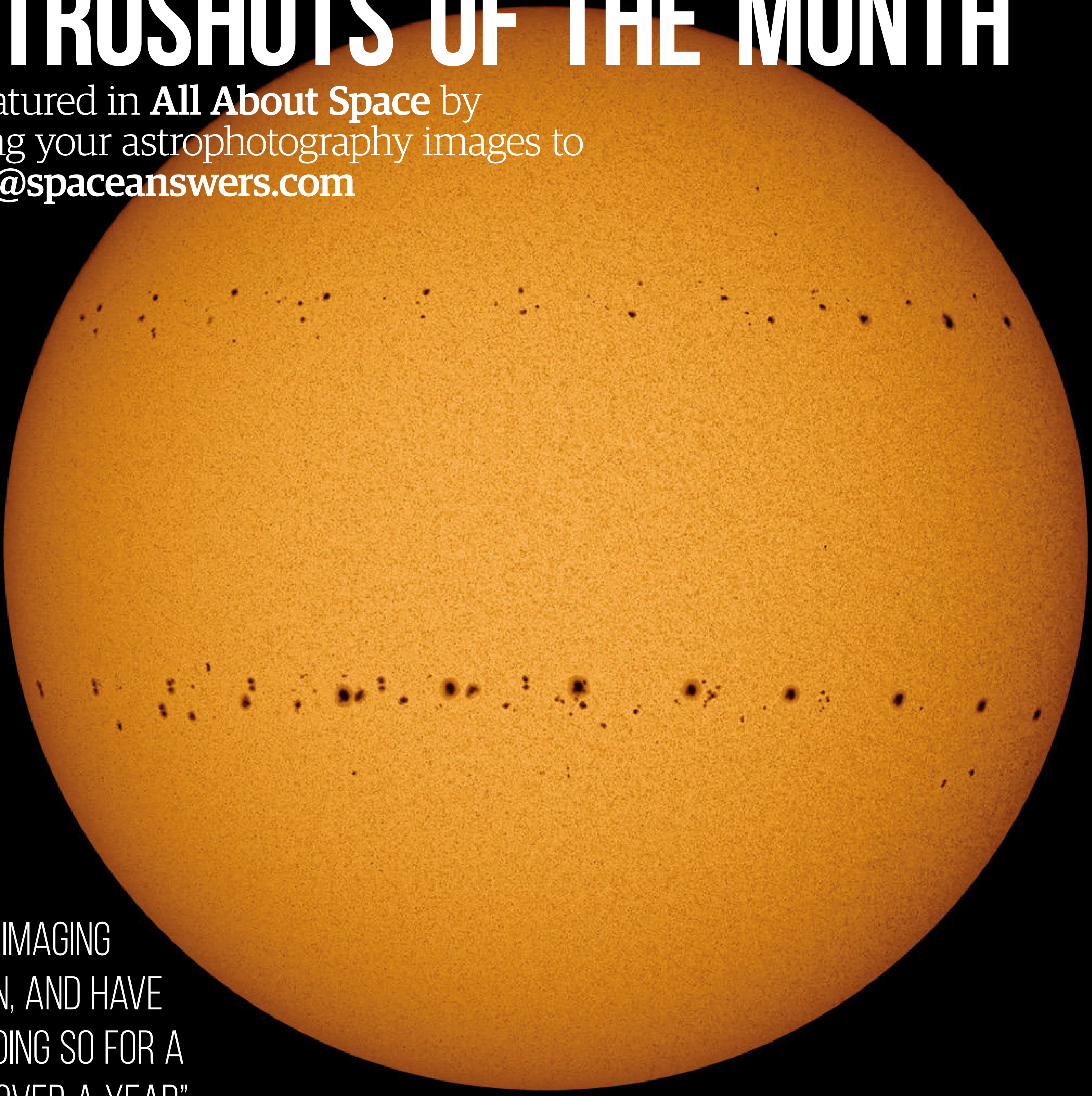
© Getty


Ursa Major (the Great Bear)

© Getty

ASTROSHOTS OF THE MONTH

Get featured in **All About Space** by sending your astrophotography images to **space@spaceanswers.com**



> "I ENJOY IMAGING THE SUN, AND HAVE BEEN DOING SO FOR A LITTLE OVER A YEAR"

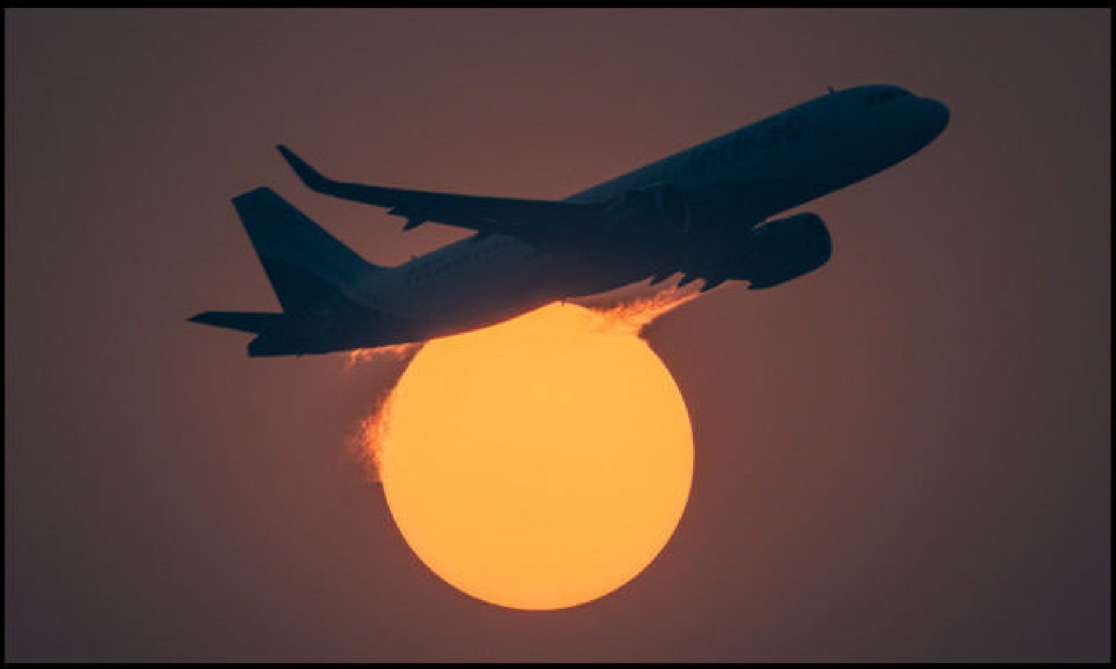
Soumyadeep Mukherjee

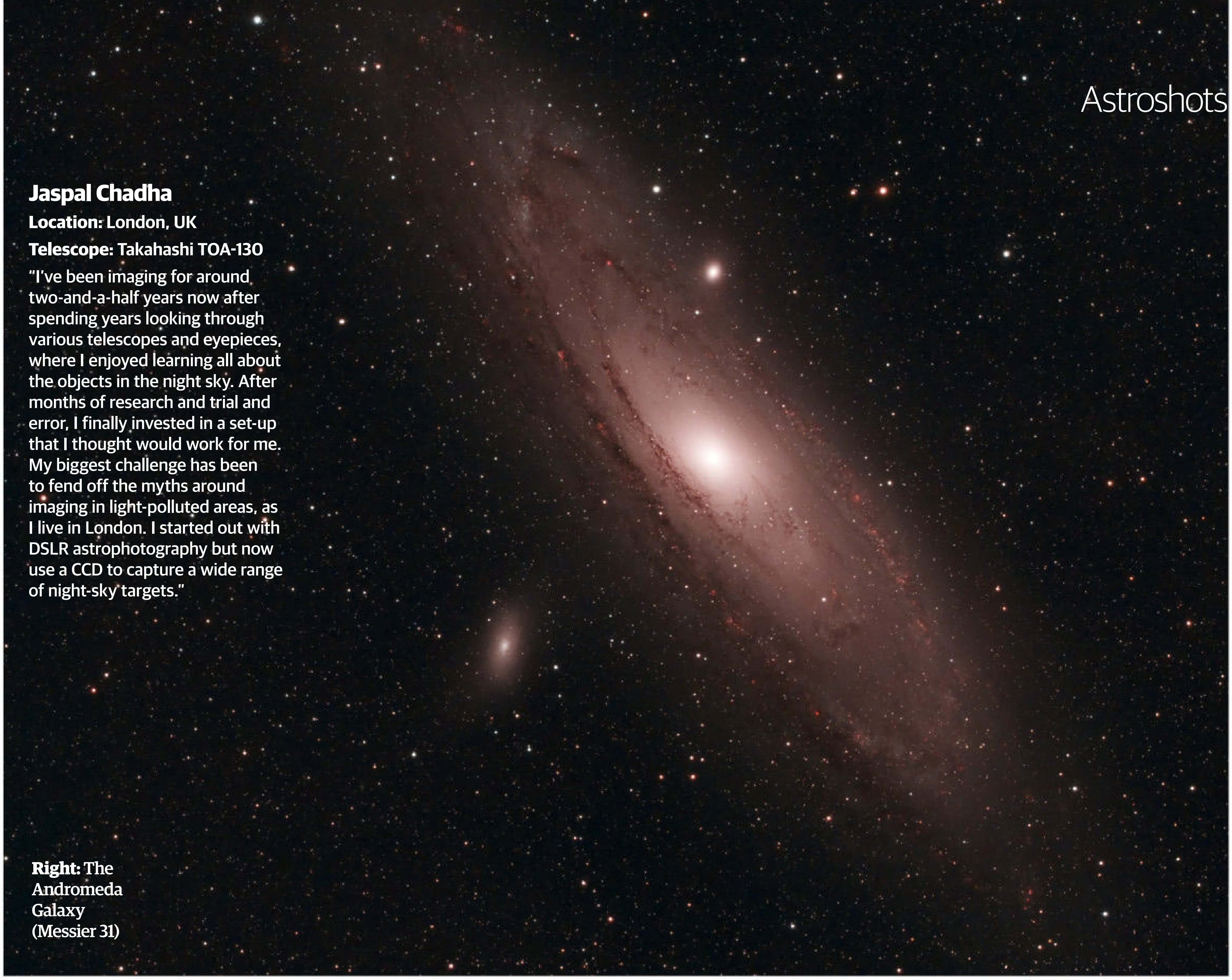
Location: Kolkata, India

"After 13 days during October 2021, from 4 to 16 October, the Sun's active region came to an end. The resulting sunspot – known as AR 2882 – generated some solar flares, ejections of electromagnetic radiation from the solar atmosphere. I enjoy imaging the Sun, and have been doing so for a little over a year. The image on the right might look like there's a solar prominence erupting from our nearest star, but it's in fact an optical illusion caused by hot fumes coming from the airliner's exhaust."

Above: AR 2882 on the surface of the Sun

Right: Optical illusion caused by an airliner's hot fumes





Jaspal Chadha

Location: London, UK

Telescope: Takahashi TOA-130

"I've been imaging for around two-and-a-half years now after spending years looking through various telescopes and eyepieces, where I enjoyed learning all about the objects in the night sky. After months of research and trial and error, I finally invested in a set-up that I thought would work for me. My biggest challenge has been to fend off the myths around imaging in light-polluted areas, as I live in London. I started out with DSLR astrophotography but now use a CCD to capture a wide range of night-sky targets."

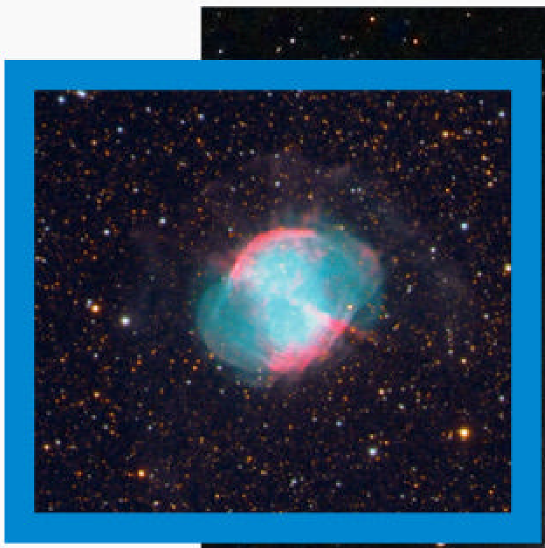
Right: The Andromeda Galaxy (Messier 31)

Jeff Johnson

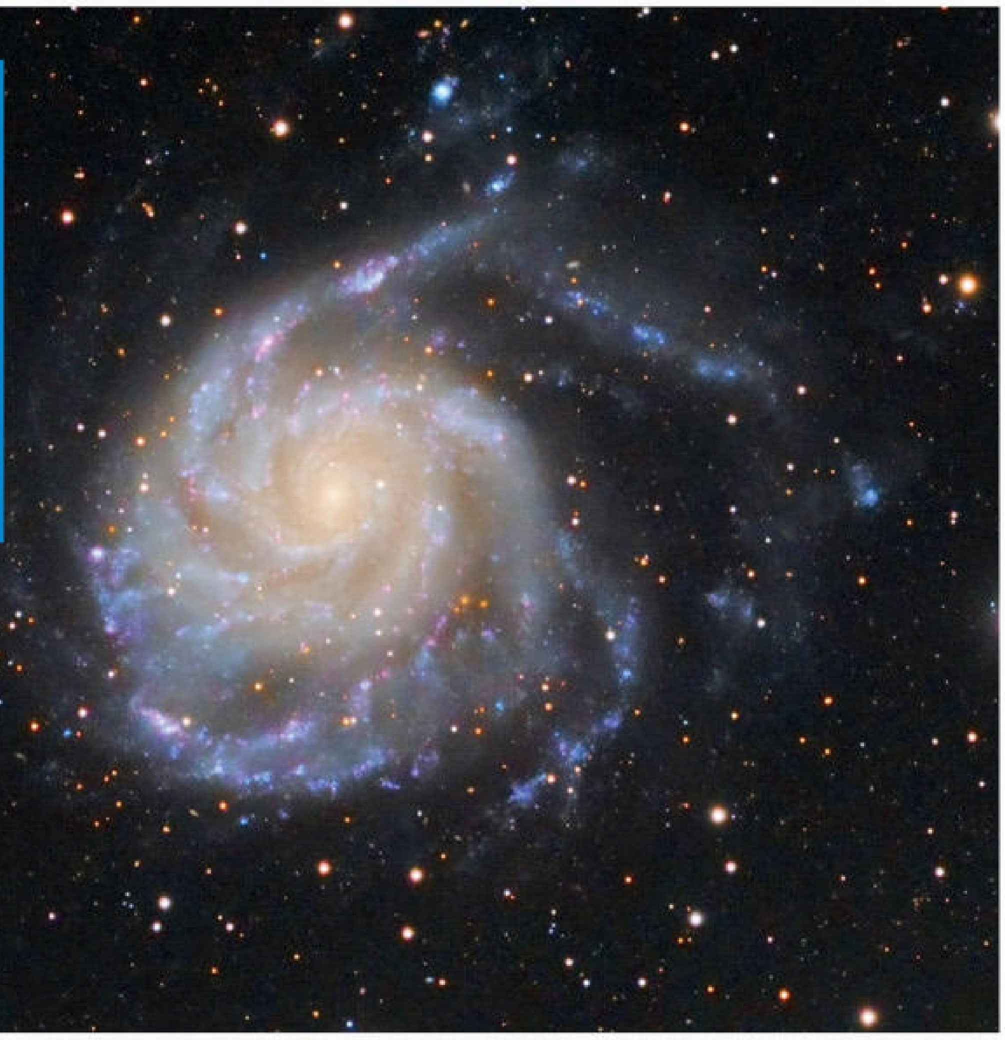
Location: Las Cruces, New Mexico

Telescope: Takahashi FS-60C

"I have a long love of astronomy, which began when I was ten years old, and I have observed the night sky for many years with binoculars and a telescope. I did my first 'real' astrophotography in 1996, when I used a 35mm SLR camera to take photographs of Comet Hyakutake. I took a tripod out into the desert, here in Las Cruces, and just experimented with different exposures. Later, I bought a ten-inch Dobsonian telescope for observing the night sky, and within a week I was taking pictures through the eyepiece for fun. Within a few more weeks, I knew I wanted to get serious with astroimaging."



Above: Dumbbell Nebula (Messier 27)



Right: Pinwheel Galaxy (Messier 101)

REVIEW

CELESTRON UPCLOSE G2 10x50 BINOCULAR

Large objective lenses and 10x magnification help this affordable piece of kit appeal to anyone wanting to start stargazing

Reviewed by Jamie Carter

BINOCULAR ADVICE

Cost: £44.99 (approx. $59.54)

From: Amazon

Optical design: Porro prism

Objective diameter: 50mm

Magnification: 10x

Exit pupil: 5mm

Eye relief: 12mm

Weight: 1,575 grams

Actual field of view: 6.8 degrees

Apparent field of view: 0 degrees

Close focus: Seven metres

Construction: Centre focus, nitrogen-filled

Coatings: Fully multi-coated

BEST FOR...

- £ LOW BUDGETS
- PLANETS
- BRIGHT DEEP SKY
- LUNAR
- STARS
- STAR CLUSTERS

How much should you pay for a binocular? Though some of the best binoculars go for low prices, you would do well to find many astronomy-centric binoculars as affordable as the Celestron UpClose G2 10x50. The pandemic has sparked an interest in home-bound activities like stargazing, and there are plenty of reasons why binoculars with the exact specifications of the UpClose G2 10x50 are just what the budding amateur astronomer needs.

All binoculars are a balance between magnification, or power, and aperture – the amount of light they collect. The Celestron UpClose G2 10x50 boasts 10x magnification, which is just about perfect for a wide field of view of the night sky, while the 50mm diameter objective lenses let in enough light at night. Whether they actually deliver on those theoretical advantages is down to the optical design, which in the Celestron UpClose G2 10x50 consists of a Porro prism – wide with tapered barrels – as opposed to a roof prism, which are H-shaped with narrow barrels. Porro prisms are generally favoured for astronomy because they're simpler optical systems and are more affordable. That's the case with the UpClose G2, which boasts such a low price that it could be an option for astronomy groups and star parties as an affordable and dependable binocular for long-term use. However, since the build quality is best described as basic, we're not convinced the Celestron UpClose G2 10x50 will last as long as pricier options.

If you do decide to buy the UpClose G2 10x50, be careful when choosing because Celestron sells a dizzying array of different products in the UpClose G2 range. There are various magnifications, objective lens sizes and prism types, with even a monocular and zoom lens offered.

The UpClose G2 10x50's design and build quality are best described as simple. Fashioned from aluminium with a matte rubber covering, they're water-resistant rather than waterproof. They're not nitrogen-purged, so it's possible they could get fogged up on occasion. Such niceties are for higher end products. We also noticed a slight looseness to the eyecups that could easily prove a weak point if this binocular were to be dropped.

Optically speaking the Celestron UpClose G2 10x50 is a compromise, with the Porro prisms dovetailing with BK7 glass, which plays second fiddle to BaK-4 for light transmission in the world of binoculars. That's also standard at this very low price.

In practice, there are a few downsides to the Celestron UpClose G2 10x50's design. The model isn't as light to hold as some roof prism binoculars, and despite the presence of some useful thumb indents and finger ridges, it is noticeably wider, too.

However, in use what the UpClose G2 10x50 mostly lacks is eye relief. The distance from your eye to the glass of the eyepiece is important to

CELESTRON
UPCLOSE G2
10-30x50 Zoom

Right: The binocular is quite basic in design, but is good for those just starting out in astronomy

The lenses use BK7 glass

Left: There isn't much eye relief, so glasses wearers might not find the binocular suitable

“OPTICALLY SPEAKING, THERE’S MUCH TO LIKE ABOUT THE CELESTRON UPCLOSE G2 10X50”

be able to see everything in the field of view, especially if you wear spectacles. That distance is called eye relief, and it’s typically between 10 and 20mm – and often adjustable within that range – in pricier binoculars. Here it’s fixed at just 12mm, while the static eyecups also feel a little narrow. If you wear spectacles, avoid the UpClose G2 10x50. However, if you don’t you’ll see enough of its 6.8-degree field of view, though the eyecups aren’t particularly comfortable over long periods of time.

The affordable price also means low-quality accessories, which here comprise very simple detachable lens caps for both the eyecups and the objective lenses, and a basic carry case that includes a shoulder strap but lacks padding. Overall it’s a very budget-conscious package, but optically speaking, there’s much to like about the Celestron UpClose G2 10x50.

Is the Celestron UpClose G2 10x50 the perfect affordable choice of binocular for observing the night sky? The 10x50 specification is the sweet spot for astronomy, but a few design and image foibles at night make the binocular less than ideal. The poor lens caps are to be expected at this low price, while the static eyecups’ lack of eye relief should bother only glasses wearers.

The chief issue with the UpClose G2 10x50 is consistent sharpness, which is easy to achieve in the centre of the field of view, but less so at the edges. A slight blur is detectable, although it’s not a huge issue when stargazing at celestial objects. In our tests, the G2 gave us excellent views of the Pleiades star cluster, Jupiter and its giant moons and the intensely bright red star Aldebaran in Taurus. With the Celestron UpClose G2 10x50 on a tripod we even managed to pick out the tiny asteroid Ceres close by, and even Uranus on the night of its annual opposition. On the bridge between the objective lenses there’s a standard binocular tripod thread, though an L-shaped tripod adapter bracket is also required.

What we didn’t notice – and had expected to – was chromatic aberration, which often shows up in affordable binoculars as a purplish line around high-contrast objects like the Moon. Kudos to Celestron and the multi-coated lenses in use here. However, we did notice that a bright Moon – and any artificial lights – do tend to cause some glare within the prisms.

Although the rubber-armoured aluminium housing is water-resistant, the Celestron UpClose G2 10x50 isn’t waterproof, and the model hasn’t been nitrogen-purged. As a consequence, the lenses could fog up slightly in the cold, though they were fine during our two-hour session in near-freezing conditions.

The 10x magnification gives a very wide field of view that’s ideal for looking within constellations and scanning the Milky Way without going too deep, but it’s hardly surprising that the UpClose G2 10x50 does feature a few imperfections.

Stargazers just starting out too often overlook binoculars, instead purchasing a telescope as soon as they possibly can. That’s a huge mistake. All experienced amateur astronomers sing the praises of a good pair of binoculars, and though the

> “THE G2 GAVE US EXCELLENT VIEWS OF THE PLEIADES STAR CLUSTER AND JUPITER AND ITS GIANT MOONS”

Celestron UpClose G2 10x50 does little more than meet the minimum requirements, the model will suit beginners well.

In theory it’s perfect, with the UpClose G2 10x50’s exact optical specifications favoured by amateur astronomers. The UpClose G2 10x50 is best thought of as a great-value entry-level binocular for all-round use and for occasional night-sky views. If you’ve never looked at the night sky through a pair of reasonably powerful binoculars then the UpClose G2 10x50 will give you that ‘wow’ moment as you scan the star fields of the Milky Way. It’s also really easy to set up, adjust and use. As such, it’s a reasonably good choice for astronomy groups on a budget, though we do worry about the longevity. However, if you know the night sky well and you’ve used many different binoculars, the Celestron UpClose G2 10x50 is unlikely to impress you. Slight foibles include some poor lens caps, a lack of eye relief and some glare from bright light.

If you can live with these slight issues then the Celestron UpClose G2 10x50 is worth considering, but don’t expect the ultimate in build quality, comfort and convenience.

There’s no doubt that 10x50 binoculars are the ideal specification for stargazing, being both portable and able to let in enough light in the dark, but you can - and perhaps should - spend a bit more than Celestron is asking for its UpClose G2 10x50 if the night sky is your primary target.

The Opticron Adventurer II WP 10x50 is a roof prism binocular with higher quality optics, as is the Celestron TrailSeeker 8x42, which offers a slightly wider field of view. For a real treat head straight for the Canon 10x42L IS WP, which comes complete with image stabilisation, or the Celestron SkyMaster 25x100 binocular, which needs to be mounted on a tripod but will give you exceptional close ups of deep-sky objects.

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FOR

- ⊕ Ideally sized for astronomy
- ⊕ Reasonably lightweight
- ⊕ Very affordable
- ⊕ Easy to adjust

AGAINST

- ⊖ Minor image distortion
- ⊖ Poor objective lens caps
- ⊖ Minimal eye relief
- ⊖ Narrow eye cups

Above: The binocular does come with a carry case, but it isn’t padded and is quite basic

Below: The binocular has a water-resistant rubber coating

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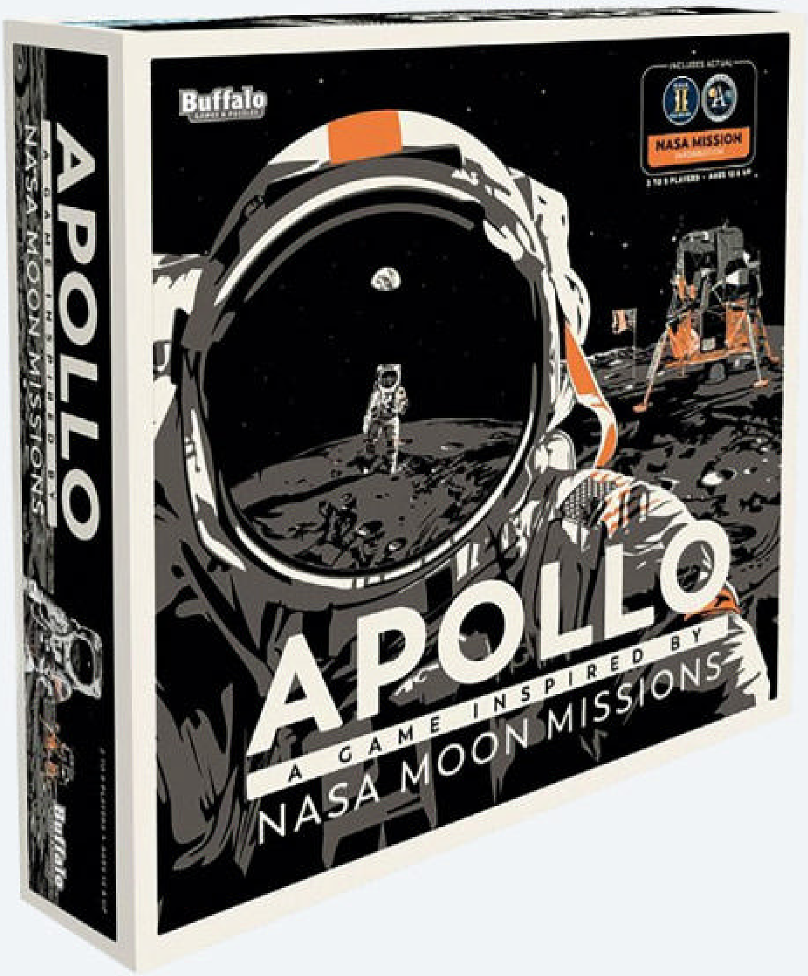

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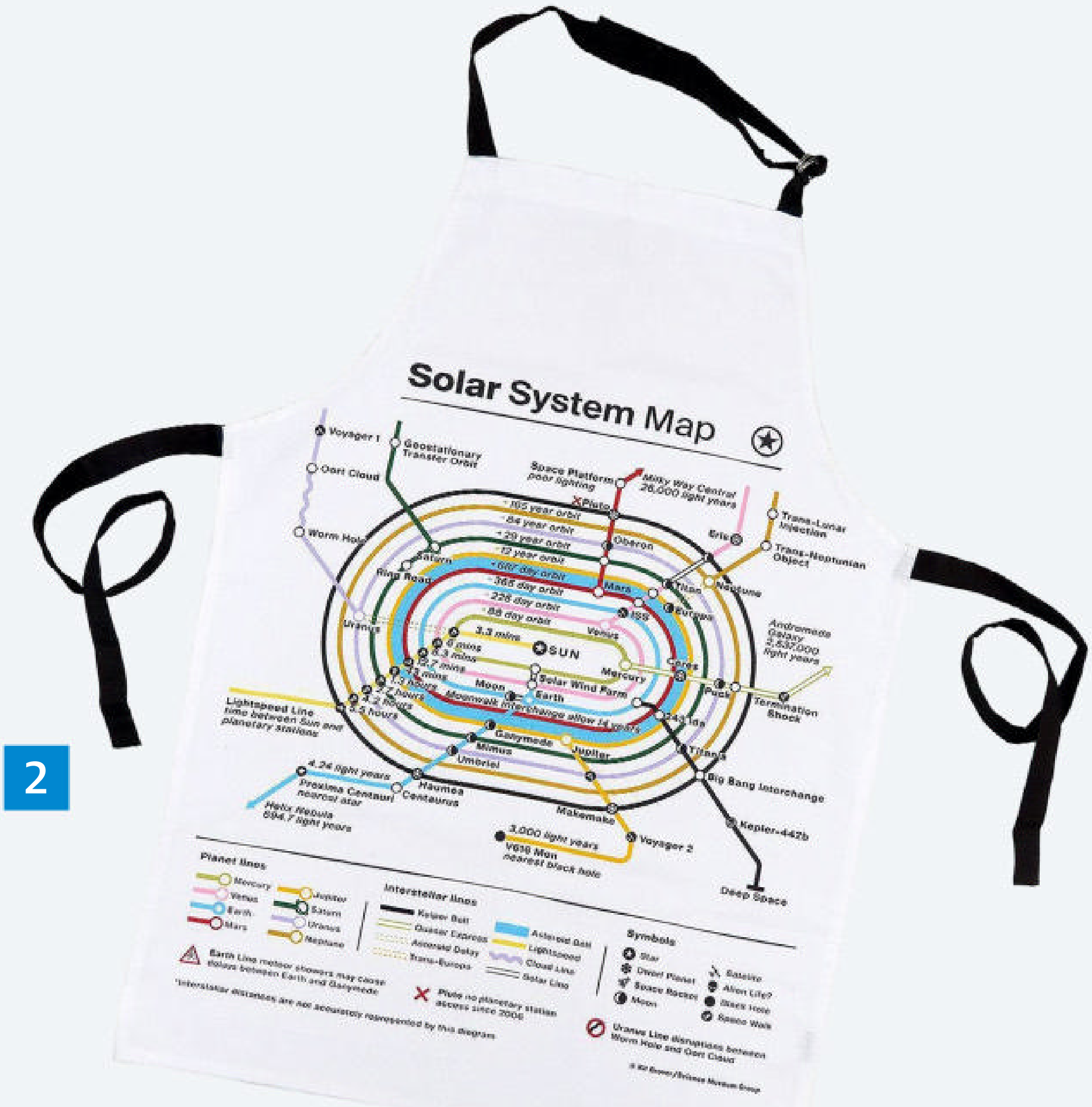

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FOR FUN

APOLLO: A GAME INSPIRED BY NASA MOON MISSIONS

Cost: £29.99 / $33.95

From: diceanddecks.com

1 Do you think you have what it takes to complete a successful trip to the Moon? Apollo invites groups of two to five players to pretend they are working on a Gemini or Apollo mission to space. The objective is to collectively complete the trip. You can either play as Mission Control or as an astronaut, tackling issues as they arise in this dice and card game. The manufacturer, Buffalo Games, says the average playtime is 30 to 60 minutes. The game contains 200 cards with over 400 questions, a timer to regulate turns and game instructions.

FOR COOKING

SCIENCE MUSEUM PLANET MAP APRON

Cost: £15.95 (approx. $21.65)

From: shop.sciencemuseum.org.uk

2 Get ready to embark on a new cooking mission – and look the part while you do – with this fun Solar System map apron from the Science Museum. Though the apron won't stop you feeling lost in the kitchen, it may help you contemplate your place in the universe. Featuring all eight primary planets, and even demoted Pluto, as well as the iconic Voyager spacecraft, the apron highlights just a handful of the universe's wonders. The apron is made in the UK from 100 per cent premium cotton and features a fabric neck and waist tie.

FOR TIMEKEEPING

KARLSSON MOON WALL CLOCK

Cost: £94.95 (approx. $129.10)

From: aspenofhereford.com

3 Time to add a bit of lunar flare to your home? This exquisite Moon wall clock will do just that. With markers detailing 3, 6, 9 and 12, the minimalist design highlights the intricate detail of the lunar surface. If you normally find yourself ticked off by the noise of clocks, the silent movement of the hour, minute and second hands will be music to your ears. The glass mirror clock is 60 centimetres (23.6 inches) in diameter; if you are enamoured with this statement timepiece, you'll be pleased to know it's also available in a Mars and Earth design.

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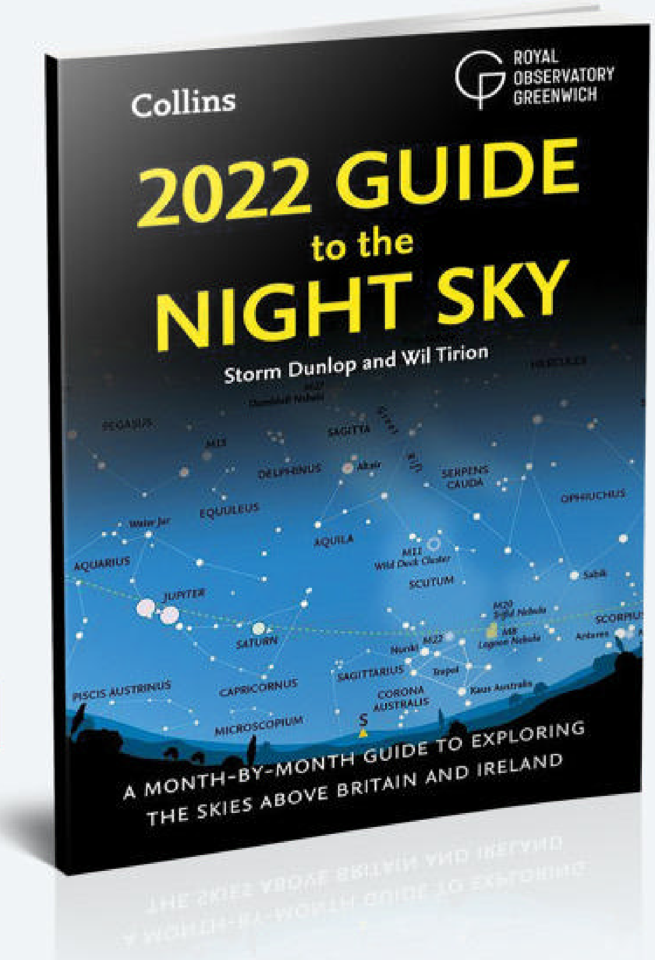
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6

FOR YOUR HOME

PLANET ARTGLASS TABLE LAMP

Cost: £115 (approx. $156.30)
From: museumselection.co.uk

4 This stunning table lamp is guaranteed to make a statement. The two hand-blown glass orbs echo Venus’ swirling shades of orange and grey. It seems only fitting that the brightest planet in the night sky is the inspiration behind this beautiful lamp with a polished chrome-coloured base. The lamp stands 49 centimetres (19.3 inches) tall and 27 centimetres (10.6 inches) wide. It requires two G9 LED clip-in bulbs, which are not included. The retailer recommends wiping it clean with a clean dry cloth.

FOR ASTROIMAGING

CELESTRON NEXYZ DX SMARTPHONE ADAPTOR KIT WITH BLUETOOTH REMOTE

Cost: £69 (approx. $93.80)
From: rothervalleyoptics.co.uk

5 This smartphone adapter kit from Celestron is the ideal accessory for those wanting to take their first steps into the world of astroimaging or digiscoping. The adapter fits any eyepiece ranging from 35mm to 60mm in diameter. The convenient design means the phone platform is fully adjustable to fit any device. The adapter can be used with telescopes, spotting scopes, binoculars, monoculars and microscopes.

FOR OBSERVERS

2022 GUIDE TO THE NIGHT SKY

Cost: £6.99 / $14.95
From: rmg.co.uk / barnesandnoble.com

6 Want to keep up to date with all the stargazing events of 2022? This practical guidebook, written and illustrated by astronomical experts Storm Dunlop and Wil Tirion, has got you covered. The book is primarily designed for Britain and Ireland but is applicable anywhere in the world between 40 and 60 degrees north, covering most of Europe, southern Canada and the northern US. The handy guide has been approved by the astronomers of the Royal Observatory Greenwich and contains a wealth of information on observing targets.

HEROES OF SPACE

CHARLES DUKE

From CAPCOM to moonwalker, Duke was a pivotal figure in the Apollo program

Duke was the tenth person to walk on the Moon

© NASA

Charles M. Duke Jr is a former NASA astronaut who explored the Moon during Apollo 16, but he is also known for his crucial role as CAPCOM – the spacecraft communicator – during the hair-raising landing of Apollo 11.

Duke entered the Air Force in 1957 after completing his training at the Naval Academy. His first assignment after advanced training was three years as a fighter-interceptor pilot with a squadron in Ramstein Air Base, Germany. When he was selected as an astronaut in 1966, Duke was an instructor at the Air Force's Aerospace Research Pilot School – a place he had graduated from just the year before.

Working at NASA, he was a member of the astronaut support crew for the Apollo 10 flight, and was then assigned as CAPCOM for Apollo 11, the first landing on the Moon. According to Duke, it was Neil Armstrong himself – the first man on the Moon – who requested Duke's presence on the radio. Apollo 11 had a dramatic landing. The crew was several miles off course, battling computer overload alarms and also running low on fuel. The Lunar Module touched down on the surface with less than 30 seconds of fuel remaining in the tanks.

"Houston, Tranquillity Base here. The Eagle has landed," Armstrong radioed on 20 July 1969. In Duke's excitement, he fumbled the communications back. "I was so excited, I couldn't get out Tranquillity Base. It came out sort of like 'Twangquillity', you know," Duke said in an interview with NASA in 1999.

Duke was subsequently a backup member of the Apollo 13 crew, where he is most famous for accidentally exposing prime crew member Ken Mattingly to German measles. Duke had been exposed by his three-year-old son. Duke, who had never had the condition before and became ill himself, went to the NASA flight surgeon. The doctor began testing all the astronauts, discovering that Mattingly had no immunity either. Mattingly was pulled from the Apollo 13 flight just days before launch.

The two men were selected as prime crew members for Apollo 16, along with John Young as commander. They lifted off on 16 April 1972, reaching lunar orbit on 19 April. Shortly after the Lunar Module Orion separated from the Command Module Casper, Mattingly discovered that the Command Module's propulsion system engine would vibrate unusually when he used backup system controls. Mission Control took hours to make a decision, but came back saying the data showed it was safe to make a landing. Young and Duke gleefully touched down on the surface to begin exploration. At the age of 36, Duke was the youngest person to set foot on the lunar surface. Duke and Young spent more than 20 hours in the Descartes Highlands, spread out over three moonwalks. The crew's primary goal was to seek out volcanic rocks, and they had received countless hours of geology training to assist them in that objective. They only found sedimentary rocks, however.

The mission went smoothly, with a few small snags: one astronaut broke a cover on the lunar rover's wheel, which meant every drive covered the astronauts with lunar regolith. Young also accidentally pulled a vital cable from a science experiment because it was hard for the astronauts to see their feet as they walked around. On his last day on the Moon, Duke placed a picture of his family on the surface. The photo includes Duke, his wife Dorothy and their sons Charles and Thomas.

Duke, Young and Mattingly splashed down safely on 27 April 1972. Duke remained with the program for three more years before retiring and undertaking several private initiatives. His work after NASA has spanned the fields of investment, real estate and even beverage distribution. He is a popular motivational speaker and is currently on the board of directors for the Astronaut Scholarship Foundation.

All About Space

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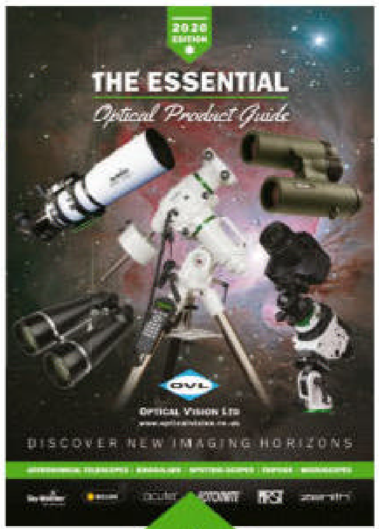

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